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16. ABSTRACT

Limnological assessments, including water and sediment chemistry, bacterial densities, zoo- and phyto-plankton and benthic macroinvertebrate community structure, and fish contaminants, were performed at 24 locations in Michigan'g nearshore waters of Lakes Superior and Huron in 1974 and 1975. The nearshore waters of Lake Superior were all oligotrophic with generally high water quality as reflected by consistently high dissolved oxygen, reactive silica and nitrate, and low phosphorus, total dissolved solids (TDS), chlorophyll a and bacterial densities. A statistical trend analysis based on 1974 through 1976 (GLECS) data indicated significant increases in the concentrations of dieldrin, DDT and mercury in Lake Superior lake trout. These same data show no statistical changes in PCB concentrations from 1974 to 1976.

The nearshore waters of Lake Huron were oligotrophic in the northern section and became mesotrophic at the southern end of the lake. Eutrophic conditions were found at Alpena harbor and Saginaw Bay. Areas of severe water quality degradation occured at Alpena and Saginaw Bay as a result of large inputs of phosphorus and TDS. A statistical analysis based on 1975 through 1978 GLECS data suggested a peak in 1976 for dieldrin, DDT and mercury in Lake Huron lake trout. The same data showed no statistical changes in PCB concentrations from 1975 through 1978.

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FOREWORD

The U. S. Environmental Protection Agency has a great concern for the nearshore waters of the Great Lakes because most of the pollutants that enter the Great Lakes pass through the nearshore zone. The processes that disperse the pollutants are very complex, therefore, a detailed description of the nearshore water quality is necessary. The nearshore environment is extremely important to the Great Lakes biota. Degradation of the nearshore environment is often the only pollutional effect that the general public perceives.

This report describes the water quality and biota of the nearshore environment along the Michigan shoreline of Lakes Superior and Huron. The authors of this report have attempted to delineate the condition of these lakes and indicate areas that have been degraded. It is hoped that the report will provide material to help design management programs for the enhancement, improvement, and protection of the nearshore waters of the Great Lakes.

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ABSTRACT

Limnological assessments, including water and sediment chemistry, bacterial densities, zoo- and phyto-plankton and benthic macroinvertebrate community structure, and fish contaminants, were performed at 24 locations in Michigan's nearshore waters of Lakes Superior and Huron in 1974 and 1975. The nearshore waters of Lake Superior were all oligotrophic with generally high water quality as reflected by consistently high dissolved oxygen, reactive silica and nitrate, and low phosphorus, total dissolved solids (TDS), chlorophyll _a_ and bacterial densities. Heavy metals and organic contaminants were low in water and sediments, except at Ontonagon, Upper Portage Entry and Munising. Phytoplankton and zooplankton communities were generally diverse and low in numbers. Plankton densities reflected seasonal changes throughout the nearshore waters and indicated nutrient enrichment at Carp River and Munising. Benthic macroinvertebrate communities indicated localized enriched areas at Ontonagon, Presque Isle, Marquette Harbor and Munising, with less extensive effects found at Lower Portage Entry and Carp River. A statistical trend analysis based on 1974 through 1976 (GLECS) data indicated significant increases in the concentrations of dieldrin, DDT and mercury in Lake Superior lake trout. These same data show no statistical changes in PCB concentrations from 1974 to 1976.

The nearshore waters of Lake Huron were oligotrophic in the northern section and became mesotrophic at the southern end of the lake. Eutrophic conditions were found at Alpena harbor and Saginaw Bay. Concentrations of chlorides, sulfates, total dissolved solids, phosphorus and chlorophyll _a_ were higher in the northern nearshore waters of Lake Huron than in Lake Superior's nearshore waters. These constituents increased from north to south while silica levels decreased. Areas of severe water quality degradation occured at Alpena and Saginaw Bay as a result of large inputs of phosphorus and TDS. Alpena was the only location where bacterial densities were consistently elevated. Areas to the south of Saginaw Bay were affected by the nutrient-rich Bay waters moving south to the lower Great Lakes. Organic and metals contaminants were generally low in water and sediments except for sediments at Cheboygan, Alpena, and particularly Harbor Beach. Sediments at the mouth of the Saginaw River were grossly polluted, but in the outer Bay sediments were unpolluted. Localized blue-green and cryptomonad algal blooms were found in the southern and very nearshore portions of the lake and in Thunder Bay. The low percentage of calanoid copepods and the abundance of rotifers and cladocerans indicated enriched conditions in the southern portions of the lake. Benthic macroinvertebrate communities indicated enriched conditions at Cheboygan, Alpena, Tawas and Harbor Beach. Metals and organic contaminants in fish were generally low or below detection. A statistical analysis based on 1975 through 1978 GLECS data suggested a peak in 1976 for dieldrin, DDT and mercury in Lake Huron lake trout. The same data showed no statistical changes in PCB concentrations

from 1975 through 1978. The GLECS data revealed no changes in dieldrin, DDT or mercury concentrations in whitefish between 1974 and 1975, but PCB concentrations were significantly greater in 1975 whitefish than 1974. The GLECS data for walleye showed significantly higher DDT and mercury concentrations in 1978 than 1974. No walleye data were available for the intervening years.

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The U. S. EPA project officer, Nelson Thomas, deserves special thanks for his review, assistance and patience throughout this project.

SECTION I

CONCLUSIONS

Background Locations - Lake Superior

1. Michigan's nearshore Lake Superior waters were oligotrophic as indicated by low total phosphorus [$\bar{x}$ = 0.007 ± 0.003 mg/l (mean ± one standard deviation)], reactive orthophosphate (0.002 ± 0.001 mg/l) and chlorophyll *a* (1.55 ± 0.36 µg/l) and non-limiting concentrations of nitrates (0.27 ± 0.03 mg/l) and dissolved silica (2.4 ± 0.2 mg/l).

2. Most heavy metals and organic contaminant concentrations in nearshore waters were near detection levels.

3. Concentrations of gamma emitting radionuclides in the nearshore waters of Lake Superior were below detection levels with total Beta emitters averaging 2 pCi/l.

4. Sediment quality was generally good with most constituents near detection levels or less than U. S. EPA dredge spoil criteria for polluted sediments. Only Presque Isle and Isle Royale sediments exceeded the EPA criteria for nickel (36 ± 52 mg/kg and 58 ± 28 mg/kg, respectively) and manganese (310 ± 108 mg/kg and 470 ± 240 mg/kg, respectively).

5. Bacterial densities were generally undetectable.

6. Phytoplankton densities were low and dominated by diatoms (especially *Asterionella* and *Cyclotella*) in the spring. In the fall the percentage of diatoms decreased due to increases in Chrysophyta (especially *Dinobryon*) and Cryptophyta (mainly *Rhodomonas*).

7. Zooplankton densities were uniformly low and included high percentages of calanoids and oligotrophic indicator species (especially *Senecella calanoides* and *Limnocalanus macrurus*). Dominant species throughout the year were *Bosmina longirostris*, *Diaptomus oregonensis*, *D. minutus* and *Cyclops bicuspidatus thomasi*.

8. The calanoid/(cyclopoid plus cladoceran) ratio was reduced in the fall due to increased numbers of the cladocerans *Holopedium gibberum* and *Daphnia retrocurva*.

9. The common occurrance of the rotifers Kellicottia, Polyarthra, and Asplanchna reflected the general oligotrophic nature of the waters.

10. The benthic communities were diverse and included pollution-intolerant indicator species. Numbers were generally less than 1,000 organisms/m² and were comprised primarily of Stylodrilus heringianus, Pontoporeia affinis, Heterotrissocladius and sphaeriids. The exception was Whitefish Point where average benthic numbers were 3757 ± 1828 organisms/m², comprised primarily of oligochaetes and P. affinis.

11. Heavy metal and organic contaminants in fish were uniformly low except for mercury, DDT and PCB. Mercury in fat lake trout exceeded the pre-January, 1978 USFDA criterion of 0.5 mg/kg at all locations. No location exceeded the new USFDA criterion of 1.0 mg/kg. DDT and PCB in fat lake trout exceeded the USFDA criteria only at Black River. Concentrations of PCB's in all fish except some mottled sculpins exceeded the 1978 Great Lakes Water Quality Agreement (GLWQA) recommended limit of 0.1 mg/kg.

Impacted Areas

12. Ontonagon

A. Ontonagon mean total phosphorus concentrations in water were in the mesotrophic range (0.015 ± 0.021 mg/l) in 1975.

B. Sediments at station 4 exceeded U.S. EPA dredge spoil criteria for total Kjeldalh nitrogen and total nickel.

C. Mean numbers of benthic macroinvertebrates were relatively low (2682 ± 2511 organisms/m²) with pollution-tolerant organisms (Limnodrilus hoffmeisteri, Aulodrilus limnobius) dominant. Pontoporeia affinis and Stylodrilus heringianus were present but in low numbers.

13. Marquette Harbor

A. Degraded benthic macroinvertebrate communities were found near the shoreline (6706 organisms/m² with 48 percent oligochaetes at station 1). Communities improved further offshore (1322 ± 1510 organisms/m² with 10 to 75 percent oligochaetes and 2 to 49 percent P. affinis.

B. Concentrations of mercury in fat lake trout (0.64 mg/kg) exceeded the pre-January, 1978 USFDA tolerance limits but fell within the new limit of

1.0 mg/kg mercury in fish flesh. PCB concentrations in fat lake trout (5.05 mg/kg) also exceeded USFDA tolerance limits at this location.

C. All fish species exceeded the GLWQA criterion for PCB. Lean lake trout exceeded the GLWQA criterion for total DDT (1.0 mg/kg).

14. Carp River

A. Carp River had elevated mean concentrations of orthophosphate (0.037 ± 0.068 mg/l), total phosphorus (0.059 ± 0.109 mg/l) and chlorophyll a (4.63 ± 1.74 µg/l) in water in 1975.

B. Diethylhexelphthalate was found in water at one station at 3.8 µg/l.

C. Fecal coliform and fecal streptococci densities were elevated at the river mouth.

D. Phytoplankton densities were elevated (2698 units/ml) above background densities with several eutrophic species present.

E. Zooplankton densities were elevated above the background numbers with 6817 organisms/m^3 found in the spring and 10,225 organisms/m^3 in the fall. Rotifer numbers were especially high at this location (5201 and 2351/m^3 in the spring and fall, respectively), indicating enriched conditions.

F. The benthic community had more taxa (9-21 per station), greater numbers (1356 ± 1405/m^2) and more pollution-tolerant forms than found at background locations.

15. Munising

A. Sediments were severely degraded with the following location mean values exceeding U. S. EPA dredge spoil criteria: oil and grease (16,840 ± 24,867 mg/kg); volatile solids (13 ± 10.4 percent); lead (80 ± 44 mg/kg); arsenic (7.3 ± 1.8 mg/kg); copper (96.6 ± 37.1 mg/kg); nickel (28 ± 9 mg/kg); total Kjeldahl nitrogen (3766 ± 691 mg/kg); zinc (134 ± 42.5 mg/kg); and chemical oxygen demand (380,000 ± 192,561 mg/kg).

B. The phytoplankton community nearest to the shore was dominated by blue-green algae throughout the year. Dactylococcopsis was dominant in the spring and was succeeded by Oscillatoria prolifica in the fall.

C. Benthic macroinvertebrates at stations nearest shore were dominated by pollution-tolerant forms with 88 percent of the organisms oligochaetes. Especially abundant were Peloscolex ferox, Aulodrilus pluriseta, Procladius, Microtendipes and Tanytarsus. At stations further from shore, oligochaetes decreased to 22 percent and pollution-intolerant forms (especially P. affinis and sphaeriids) became dominant (88 percent).

D. Concentrations of mercury in fat lake trout (0.71 mg/kg) exceeded pre-January, 1978 USFDA tolerance limits but not the new USFDA limit of 1.0 mg/kg mercury in fish flesh. Levels of PCB in fat lake trout (5.05 mg/kg) also exceeded USFDA tolerance limits.

E. All fish species except mottled sculpins exceeded the GLWQA recommended tolerance limit for PCB. Lean lake trout exceeded the GLWQA limit for DDT.

Background Locations - Lake Huron

1. Nearshore Lake Huron waters were oligotrophic in the northern areas but approached mesotrophy in the southern portion. Low lakewide concentrations of total phosphorus (0.007 ± 0.001 mg/l), reactive orthophosphate (0.003 ± 0.002 mg/l) and chlorophyll *a* concentrations (2.3 ± 0.89 µg/l) reflect the oligotrophic quality of these waters. Nitrates (0.269 ± 0.022 mg/l) and reactive silica (1.2 ± 0.4 mg/l) were abundant in the northern portion with lower concentrations in the southern portion of the lake.

2. Concentrations of most heavy metals and organic contaminants in water were near or below detection. The PCB concentration in water at one Harrisville station was 0.08 µg/l.

3. Sediment quality was generally good with most parameters near or below detection and within U. S. EPA dredge spoil criteria.

4. Bacterial densities were generally undetectable at background locations.

5. Phytoplankton communities were dominated by diatoms. Algal abundances at northern Lake Huron locations averaged one-third to one-half the lakewide mean with an overall north to south increase. Lexington may be classified as eutrophic, based on algal numbers which were twice the lakewide mean.

6. Spring zooplankton densities (13,444 ± 14,331 organisms/m^3) were numerically greater than fall densities (4545 ± 2164 organisms/m^3) although not statistically different. There was a general increase from north to south. Rotifers were more abundant close to shore (station 1 average 2824/m^3) than further offshore (661/m^3). The dominant zooplankton species were *Bosmina longirostris*, *Diaptomus oregonensis*, *D. minutus* and *Cyclops bicuspidatus thomasi*.

7. The benthic macroinvertebrate community at the northernmost location (Detour) was completely dominated by oligotrophic indicator species (especially *Stylodrilus heringianus* and *Heterotrissocladius*) and lacked tubificids. Presque Isle and Harrisville were also dominated by oligotrophic indicator species but pollution-tolerant or mesotrophic indicator tubificids and chironomids were present in low numbers. Lexington, south of Saginaw Bay (and affected by its waters), was completely dominated by mesotrophic indicator species. *Pontoporeia affinis*, the primary profundal organism, was exceptionally sparse in most nearshore waters (not found at Harrisville and Lexington and only 19/m^3 at Detour).

8. Heavy metals and organic contaminants were generally at or below detection levels in all fish species at all locations. Concentrations of PCB and DDT were highest in salmonids, while mercury was highest in yellow perch.

Impacted Areas

9. Cheboygan

   A. The water quality at Cheboygan was enriched as indicated by elevated chlorophyll a (6.6 ± 8.5 μg/l) concentrations and low nitrates (0.18 ± 0.05 mg/l) and reactive silica (2.0 ± 1.6 mg/l).

   B. In sediments, oil and grease (2600 mg/kg), zinc (140 mg/kg), and TKN (2500 mg/kg) exceeded U. S. EPA dredge spoil criteria at two, one and one stations, respectively.

   C. Spring phytoplankton communities were dominated by cryptophytes with lesser numbers of blue-greens and diatoms. In the fall, diatoms were dominant with the Chrysophytes second most abundant.

   D. Zooplankton populations were not dominated by calanoids, yielding a low calanoid/(cyclopoid plus cladoceran) ratio in the spring (0.41) and a very low ratio in the fall (0.28) indicating enriched conditions.

   E. The benthic community at stations nearest shore was diverse and composed of abundant pollution-tolerant oligochaetes (36 percent) and chironomids (14 percent). *P. affinis* was not present, but at stations further offshore intolerant species (especially *Heterotrissocladius*) were found in low numbers.

10. Saginaw Bay

    A. Saginaw Bay was considered eutrophic based on high total phosphorus (0.018 ± 0.011 mg/l), and chlorophyll a (60.5 ± 46.8 μg/l), and low nitrate (0.14 ± 0.11 mg/l) and reactive silica (0.7 ± 0.4 mg/l). In addition, 79 percent of the total nitrogen found in Saginaw Bay was in the organic form.

    B. River-mouth sediments were grossly polluted with copper (46 mg/kg), arsenic (4.2 mg/kg), chromium (36 mg/kg), zinc (195 mg/kg), nickel (42 mg/kg), lead (67 mg/kg), manganese (460 mg/kg), COD (87,000 mg/kg), TKN (2200 mg/kg), and PCB (315 μg/kg).

    C. Phytoplankton communities were dominated by green and blue-green algae, especially *Ulothrix* and *Oscillatoria*, respectively.

    D. Zooplankton populations were dominated by cyclopoids and cladocerans yielding low calanoid/(cyclopoid plus cladoceran) ratios (0.41 spring and 0.35 fall).

11. Tawas

A. Water quality was moderately enriched as indicated by chlorphyll _a_ (3.6 ± 1.7 µg/l) and reactive silica (1.2 ± 0.3 mg/l) concentrations.

B. The phytoplankton community was dominated by abundant eutrophic green algae (_Ulothrix_) near the river but improved further offshore.

C. The benthic macroinvertebrate community was dominated by pollution-tolerant species (especially _Peloscolex_ _ferox_, _Pseudochironomus_, _Chryptochironomus_ gr.) at stations nearest shore but at outer stations oligotrophic indicator species (notably _Stylodrilus heringianus_) were present.

D. Whitefish and yellow perch flesh (0.22 and 0.20, respectively) exceeded the GLWQA recommended tolerance limit for PCB.

12. Harbor Beach

A. Water quality inside the breakwater was moderatley enriched as reflected by mean chlorphyll _a_ (5.4 ± 1.2 µg/l) and total phosphorus (0.012 ± 0.007 mg/l) concentrations.

B. Sediments exceeded U.S. EPA dredge spoil criteria for TKN (2573 ± 1466 mg/kg), COD (62,000 ± 22,315 mg/kg), oil and grease (1350 ± 70.7 mg/kg), zinc (126 ± 57.2 mg/kg), arsenic (5.2 ± 1.4 mg/kg), nickel (31 ± 6 mg/kg), and iron (34,000 ± 29,720 mg/kg). Copper manganese, chromium and PCB (18 to 27 µg/kg) were elevated but did not exceed U.S. EPA dredge spoil criteria.

C. Zooplankton populations indicated enriched conditions by low calanoid/(cyclopoid plus cladoceran) ratios (0.44 spring, 0.43 fall) and elevated rotifer numbers (5524/m^3 in the fall).

D. The benthic macroinvertebrate community within the breakwall was indicative of degraded water quality with 86 percent by abundance pollution-tolerant oligochaetes. Stations outside the breakwall were dominated by oligotrophic indicator species (especially _Stylodrilus heringianus_). _P. affinis_ was not found at any station.

13. Alpena

A. Water quality at Alpena was enriched as reflected by elevated total phosphorus (0.039 ± 0.039 mg/l in 1974 and 0.018 ± 0.009 mg/l in 1975), chlorophyll a (8.7 ± 4.0 μg/l in 1974 and 11.3 ± 5.5 μg/l in 1975) and low nitrates (0.14 ± 0.11 mg/l in both years).

B. PCBs in the water were found at one station at 0.02 μg/l.

C. Mean sediment TKN (1033 ± 469 m/gkg) and oil and grease (1180 ± 783 mg/kg) exceeded U.S. EPA dredge spoil criteria, as did arsenic at half of the stations sampled.

D. Phytoplankton communities reflected enriched conditions with high total numbers four times the lakewide mean.

E. Zooplankton communities in the fall indicated enriched conditions as reflected by a low calanoid/(cyclopoid plus cladoceran) ratio (0.27).

F. The benthic community was degraded. Sphaeriids decreased from 18 percent of the total population in 1957 to 6 percent in 1975. Oligotrophic indicator species were present in very low numbers and only found at the outermost stations.

G. Brown trout, chinook salmon, whitefish and yellow perch in 1974 and 1975 exceeded the GLWQA recommended tolerance limits for PCB.

Trends in Fish Contaminants

1. In Lake Superior, lake trout was the only species with sufficient data for analysis. The most recent GLECS data covered a period from 1974 to 1976. The lake trout data in Lake Superior were collected from two subspecies (fat and lean). Fat lake trout had significantly higher concentrations of all contaminants than did lean lake trout. The concentrations of dieldrin, DDT and mercury in the lean and fat lake trout combined were significantly higher in 1976 than 1974. Concentrations of PCB however, did not change significantly during this same period.

2. In Lake Huron adequate data were available for analysis of lake trout (1975-1978), whitefish (1974 and 1975) and walleye (1974 and 1978).

   In Lake Huron lake trout, dieldrin, DDT and mercury concentrations appear to have peaked in 1976 followed by an apparent decline using the most recent (1975-1978) data. Concentrations of PCB however, did not change signficantly from 1975 to 1978. For whitefish no significant changes occurred in the concentrations of dieldrin, DDT and mercury in Lake Huron. A significant increase in PCB concentrations in whitefish occurred from 1974 to 1975.

3. In Lake Huron walleye, a significant increase in DDT and mercury concentrations in 1978 over 1974 was observed. However, without the intervening years data, prediction of trends is difficult. The maximum mercury concentration in walleye collected in the northern portion of Lake Huron nearly exceeded the action level. Dieldrin and PCB were not tested for in 1974 walleye.

SECTION II

RECOMMENDATIONS

1. Most impacts found in the nearshore areas of Lakes Huron and Superior were the result of nutrient inputs from wastewater treatment facilities (WWTP). Many of these WWTPs have been or are now being upgraded to meet their NPDES limits. The following areas should have follow-up studies to document improvements in water quality:

   A. Alpena - The municipal WWTP has been upgraded to secondary treatment with phosphorus removal. In addition, the Abitibi paper company has changed its treatment process to reduce nutrient inputs. An interim permit has been issued and further improvements are planned.

   B. Cheboygan - The present municipal WWTP has only primary treatment, but a new facility is under construction and will be on line by 1980.

   C. Harbor Beach - The municipal WWTP presently has secondary treatment but is undersized. A facility plan for a new structure has been submitted for approval. More efficient treatment should eliminate the present bacterial contamination.

   D. Marquette - The municipal WWTP has impacted the Carp River and Marquette Harbor. The plant is being upgraded and will be operational in two or three years.

   E. Munising - The present municipal WWTP has been upgraded to secondary treatment with phosphorus removal. The Kimberly Clark paper company has improved its treatment facility and is now in compliance with its NPDES limits.

   F. Ontonagon - The municipal WWTP effluent formerly discharged to Lake Superior now goes to the Hoerner-Waldorf paper company. However, since Hoerner-Waldorf discharge is not meeting water quality standards, and is in gross violation of its NPDES permit the problem remains. Recent negotiations with the company may soon resolve the problem.

   G. Tawas - The municipal WWTP presently has primary treatment only, but will be upgraded within several years.

2. Saginaw Bay is eutrophic and loadings to the Bay are decreasing. The entire southern basin of Lake Huron has been impacted by Saginaw Bay. Intensive efforts should be made to improve the water quality of Saginaw Bay before the southern basin becomes eutrophic.

3. New funding for the GLECS studies should be provided to monitor the elevated PCB and mercury concentrations in fat lake trout from Lake Superior. Other fish species should be monitored and the remainder of the samples collected during 1976-1978 analyzed to document the direction of changes in these residual bioaccumulative contaminants.

4. New fish collections should include area MS-5 in Lake Superior where very highly contaminated lake trout were previously collected.

5. Fish already collected from Lake Huron in 1976-1978 should be analyzed to reassess the increase in mercury contamination in walleye. The direction of changes in the concentrations of DDT, PCB, mercury and dieldrin in lake trout and whitefish also need verification.

SECTION III

INTRODUCTION

The Laurentian Great Lakes collectively constitute the world's largest reservoir of fresh water and are a critical resource for the future development of the United States and Canada. While less than four percent of the United States land area lies within the Great Lakes watershed, it supports more than 14 percent of the United States population. Increasing population densities in the watershed will require increased volumes of high quality water for municipal, industrial, commercial and agricultural expansion. At the same time, there will be an increasing demand for high quality water for drinking, swimming, boating, fishing and other recreational pursuits. The necessity for high quality water to maintain existing natural ecosystems overlays these interwoven and often conflicting uses.

Future management strategies designed to utilize, protect and, where needed, improve the Great Lakes water resources must be based on up-to-date and comprehensive information. To provide such information, the Biology Section of the Michigan Department of Natural Resources, Water Quality Division (WQD), conducted water quality surveys in the Michigan nearshore waters of Lakes Superior and Huron during the spring and fall of 1974 and the summer of 1975.† The primary objectives of this project were: (1) to establish background levels of chemical constituents and assess existing biological communities in Michigan's nearshore Great Lakes waters, and (2) to document cultural influences on the quality of these waters.

The nearshore waters in this project were roughly defined as those waters within 5 kilometers (km) of the shoreline. Although they comprise only a small portion of a lake's volume, nearshore waters are a focal point for limnological studies because they are the site of complex interactions between the lake's watershed and the deep water or limnetic zone. The nearshore or littoral waters are extremely productive and serve as spawning, nursery and feeding areas for fish and other organisms. Benthic and planktonic animals found in nearshore waters are vital food chain links and are generally sensitive to changes in water quality. Physical processes, such as wave-induced mixing, coastal currents and thermal bars, may act in the nearshore waters to disperse or contain watershed inputs.

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†These nearshore surveys were part of a comprehensive assessment of these lakes performed under the auspices of the Upper Lakes Reference Group of the International Joint Commission.

Water in sheltered embayments and harbors is isolated in varying degrees from offshore physical processes and may not readily mix with other nearshore waters or the open lake. This can cause extensive chemical and physical variability within these embayments. Therefore, these embayments and harbors often exhibit physical and chemical characteristics significantly different from adjacent nearshore and open-water areas.

Consequently the nearshore waters, especially the embayments, are the first to be adversely impacted by waste discharges and can thereby serve as an early warning of impacts on whole-lake water quality.

SECTION IV

METHODS

Sampling Design

In 1974, twenty-one locations and in 1975, twenty-three locations in the nearshore waters of Lakes Superior and Huron were sampled (Figure 1). The locations selected included areas of potential cultural impact and areas outside direct human influence. The impacted locations were sampled to identify the extent of degradation from local major discharges which enter the lake via rivers. The background locations were sampled to determine background values of water and sediment chemical constituents and the diversity and density of organisms comprising the biological communities. The term "background" is defined as locations where man's impact was judged to be minimal when compared with those locations described as impacted.

In 1974, the locations were sampled in both spring and fall. Spring samples were collected between June twelve and July third. Fall samples were collected between August 23 and September 16. One fall station was sampled on October eighth. Sampling stations were arranged in three tiers at each location (Table 1, Table A-1, Figure 2). The first tier consisted of one station. At impacted locations, attempts were made to locate this station at the interface of the river and the lake proper. At background locations, this station was located nearest shore. The second tier of stations, numbered 2 through 4, was arranged in a line parallel to the shoreline, with station 3 located directly lakeward from station 1. This tier of stations was located 60-180 meters (m) from shore at impacted locations and 0.8 to 1.2 km from shore at background locations. The third tier of stations, numbered 5 through 7, was arranged in a line parallel to the shoreline, with station 6 directly lakeward from stations 1 and 3. This tier was located 1.6 to 4.8 km offshore at all locations. At selected impacted areas, additional stations were established to evaluate the biological community.

The station arrays at five locations were modified to accomodate special local conditions. Upper and Lower Portage Entries and Eagle Harbor had four stations arranged similarly to stations 1 through 4 of the above sampling design (Figure 2). Isle Royale had four stations located on the northern shoreline of Amygdaloid Island (Figure 2). The Saginaw Bay sampling design was reduced because of extensive sampling conducted by other agencies. Four stations were located along the major axis of the Bay, with station 1 at the interface with the Saginaw River and stations 2 through 4 extending to the middle of the outer Bay (Figure 2).

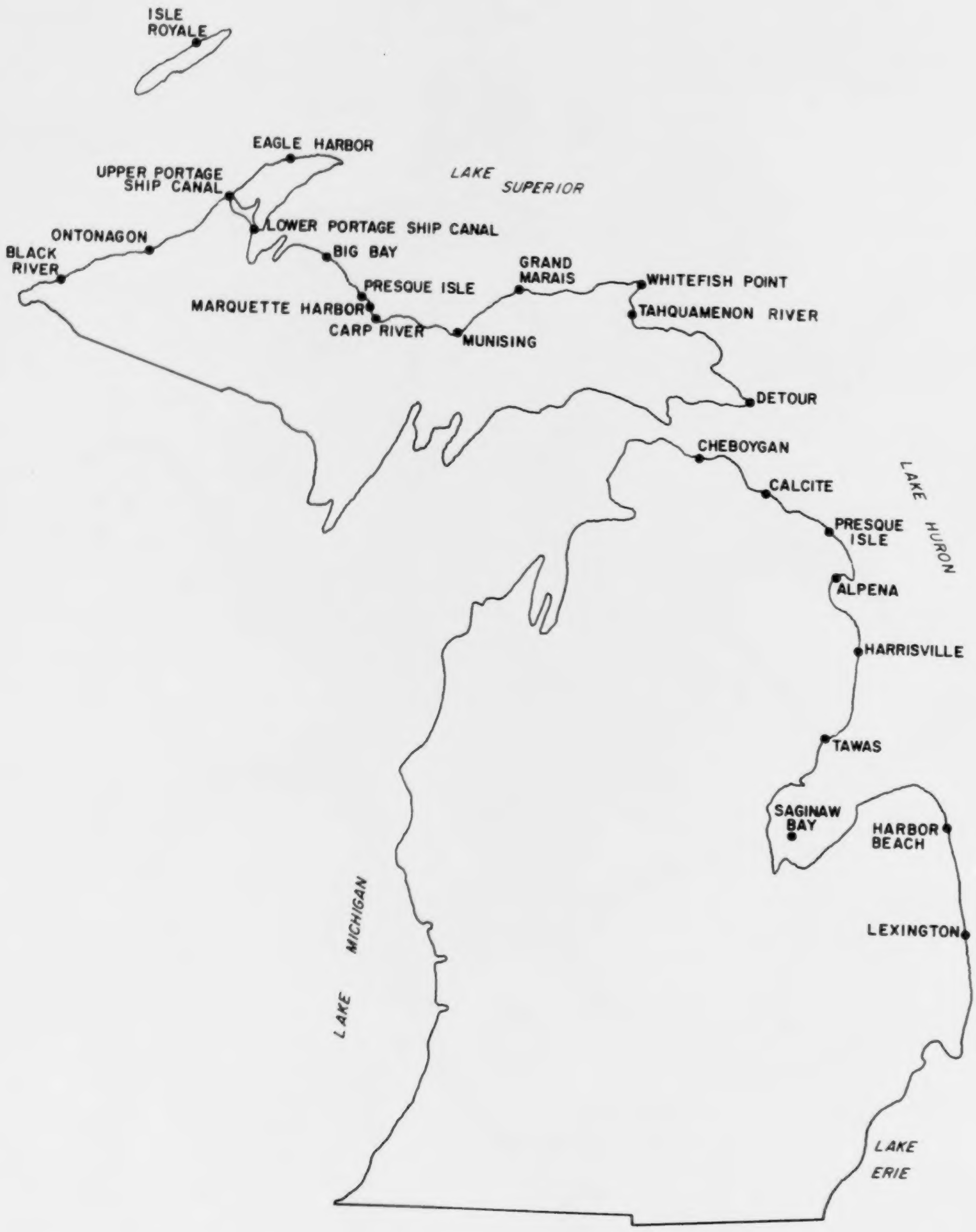
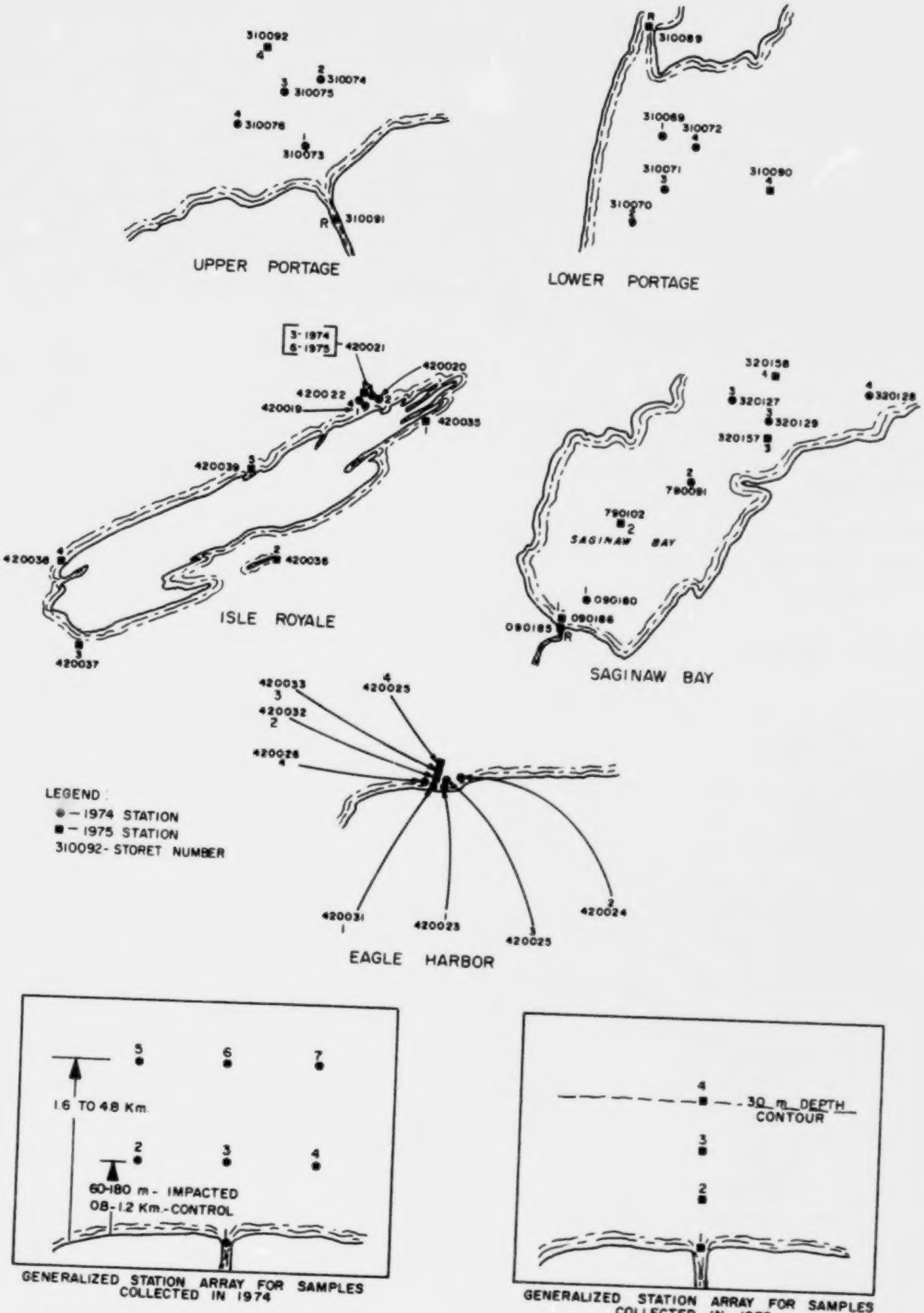

ISLE ROYALE
EAGLE HARBOR
LAKE SUPERIOR
UPPER PORTAGE SHIP CANAL
LOWER PORTAGE SHIP CANAL
ONTONAGON
BLACK RIVER
BIG BAY
GRAND MARAIS
WHITEFISH POINT
PRESQUE ISLE
MARQUETTE HARBOR
TAHQUAMENON RIVER
CARP RIVER
MUNISING
DETOUR
CHEBOYGAN
CALCITE
LAKE HURON
PRESQUE ISLE
ALPENA
HARRISVILLE
TAWAS
SAGINAW BAY
HARBOR BEACH
LAKE MICHIGAN
LEXINGTON
LAKE ERIE

Figure 1 Sampling Stations in the nearshore waters, Lake Superior and Huron, 1974 and 1975

Table 1. Sampling locations and number of stations per location in the nearshore waters, Lakes Superior and Huron, 1974 and 1975.

Location	Number of Stations Sampled		
	Spring-74	Fall-74	Summer-75
Lake Superior			
Impacted			
Ontonagon	7	7	5
Upper Portage	4	4	2
Lower Portage	4	4	2
Presque Isle	7	7	5
Carp River	7	7	5
Munising	7	7	5
Background			
Black River	7	7	2
Isle Royale	4	3	6
Eagle Harbor	4	4	4
Big Bay	7	7	2
Grand Marais	7	7	4
Whitefish Point	6	6	-
Additional (Sampled only in 1975)			
Marquette Harbor	-	-	4
Tahquamenon River	-	-	2
Lake Huron			
Impacted			
Cheboygan	7	7	5
Alpena	7	7	7
Tawas	7	7	2
Saginaw Bay	4	4	5
Harbor Beach	7	7	4
Background			
Detour	7	7	4
Presque Isle	7	7	4
Harrisville	7	7	4
Lexington	7	7	4
Additional (Sampled only in 1975)			
Calcite Harbor	-	-	4
Total	132	131	89


310092
310074
310075
310076
310073
R
310091
UPPER PORTAGE
R
310089
310069
310072
310071
310090
310070
LOWER PORTAGE
3-1974
6-1975
420021
420020
420022
420019
420035
420039
420038
420036
420037
ISLE ROYALE
320158
320127
320128
320129
320157
790091
790102
SAGINAW BAY
090180
090186
090185
R
SAGINAW BAY
420033
420025
420032
420026
420031
420023
420025
420024
EAGLE HARBOR
LEGEND:
● – 1974 STATION
■ – 1975 STATION
310092 - STORET NUMBER
1.6 TO 4.8 Km.
60-180 m - IMPACTED
0.8-1.2 Km.-CONTROL
30 m DEPTH CONTOUR

GENERALIZED STATION ARRAY FOR SAMPLES COLLECTED IN 1974

GENERALIZED STATION ARRAY FOR SAMPLES COLLECTED IN 1975

Figure 2 Sampling array for locations sampled in the nearshore waters, Lake Superior and Huron, 1974 and 1975.

Data collected in the rivers at the interface of the lake in 1974 are not included in this report, since they do not reflect typical nearshore conditions. Although these data are not included, they are available upon request. They are available in the WQD files and on the U. S. EPA STORET computerized water-quality-data-storage system. The STORET station numbers for all stations are given in Table A-1 and Table A-2 in the appendix.

In 1975, the locations were sampled only in the summer. Summer samples were collected from June nine second to August sixteenth. The station array at each location was reduced to four stations positioned on a transect perpendicular to the shoreline (Figure 2, Table A-2). At impacted locations, attempts were made to locate station 1 at the interface of the river and the lake proper. At background locations, station 1 was located near shore in less than 8-m of water.

The station arrays at eight locations were modified to accomodate special local conditions. Upper and Lower Portage Entries, Black River, Big Bay, Tahquamenon River and Tawas were sampled at only one station. Isle Royale and Alpena were sampled at six stations.

Additional water samples were taken in 1975 from selected rivers for heavy metals and organic contaminants analysis (Table A-6).

Physical and Chemical Water Constituents

In 1974, water samples were collected from 3 depths: 1-m below the surface, mid-depth and 1-m above the bottom. Mid-depth collections were deleted at shallow-water stations. Descriptive statistics for the physical and chemical water constituents were computed using all stations within a location, excluding station 1 (Table A-3). Station 1 was not included because it was always close to the point source (where present) and often did not reflect nearshore water quality. Detailed correlation coefficient matrices were generated using combined spring and fall data for statistically significant combinations of paired water quality parameters (Table A-4 and Table A-5).

In 1975, water was collected from 1-m below the surface and 1-m above the bottom, with all stations included in the calculations of the descriptive statistics (Table A-6).

For both 1974 and 1975, 8 groups of physical and chemical water quality variables were determined. These variables are listed in Table 2, along with descriptions of analytical methods, sensitivity limits and literature citations for specialized procedures. All samples, except those to be analyzed for heavy metals contaminants in 1975, were iced and flown to the Environmental Protection Bureau Laboratory in Lansing for analysis. Table 3 shows the sampling patterns for all groups of variables surveyed at impacted and background locations in 1974 and 1975. Table 4 shows the sampling devices, field preservatives and other information pertinent to sample collection.

Table 2. Methods used to analyze selected water and sediment constituents and fish contaminants in Lakes Superior and Huron, 1974 and 1975

Water variables

Group/Variable	Analytical Method	Sensitivity	Reference
IN-SITU:			
Temperature	Martek MK II	0.1 °C	
Dissolved Oxygen	Martek MK II	0.1 mg/l	
Conductivity	Martek MK II	1 µmho/cm	
pH	Martek MK II	0.01 SU	
NUTRIENTS:			
Ammonia-N	Automated Phenate	1 µg/l	EPA p. 168
Nitrate-N	Automated Cadmium Reduction	10 µg/l	EPA p. 207
Nitrite-N	Diazotization Colorimetric	1 µg/l	EPA p. 215
Total Kjeldahl-N	Block digestor Automated Salicylate	2 µg/l	
Organic-N	Kjeldahl-N minus Ammonia-N	2 µg/l	
Total-N	Sum of nitrogen fractions	-	
Reactive orthophosphate	Automated Single Reagent Ascorbic Acid Reduction	2 µg/l	EPA p. 256
Total Phosphorus	Block Digester Automated Single Reagent	2 µg/l	EPA p. 256
Reactive Silica	Automatic Molybdosilicate	0.1 mg/l 0.1 mg/l	EPA p. 249 Std. Md. p. 302
GENERAL CHEMISTRY			
pH	Electrometric	0.01 SU	Std. Md. p. 500 A.S.T.M. p. 186 EPA p. 239
Conductivity	Wheatstone Bridge Corrected to 25°C	1 µmho/cm	Std. Md. p. 323 A.S.T.M. p. 128 EPA p. 275
Alkalinity, Total	Automated Methylorange	1 mg/l	EPA p. 5
Hardness, Total	EDTA Titration	1 mg/l	Std. Md. p. 179 A.S.T.M. p. 169 EPA p. 68
Chemical Oxygen Demand	Dichromate, Test Tube	0.2 mg/l	Std. Md. p. 495 A.S.T.M. p. 472 EPA p. 21
Turbidity	Hach Turdibimeter	0.1 JTU	Std. Md. p. 350 A.S.T.M. p. 231 EPA p. 295
Total Dissolved Solids	65% of Sp. Conductance Sum of Constituents		
Suspended Solids	Gravimetric, Glass Fiber Filtered, 180°C	1 mg/l 1 mg/l	Std. Md. p. 38 EPA p. 266
Suspended Volatile Solids	Gravimetric, 550°C	1 mg/l	Std. Md. 536 EPA p. 272

continued

Table 2. (continued)

WATER VARIABLES

Group/Variable	Analytical Method	Sensitivity	Reference
MAJOR IONS:			
Calcium	EDTA Titration	1 mg/l	Std. Md. p. 84
			EPA p. 19
Magnesium	Atomic Absorption	0.1 mg/l	Std. Md. p. 210
			A.S.T.M. p. 351
			EPA p. 114
Sodium	Atomic Absorption	0.1 mg/l	EPA p. 147
Potassium	Atomic Absorption	0.01 mg/l	EPA p. 143
Iron	Flameless AA	0.0004 mg/l	Std. Md. p. 210 (Duluth)
	Atomic Absorption	0.005 mg/l	A.S.T.M. p. 351
			EPA p. 110
Manganese	Atomic Absorption	0.001 mg/l	Std. Md. p. 210
			A.S.T.M. p. 351
			EPA p. 116
Chlorides	Automated Ferric thiocyanide	0.1 mg/l	EPA p. 31
Sulfates	Barium Chloride	0.1 mg/l	Std. Md. p. 334
	Turbidimetric		A.S.T.M. p. 428
			EPA p. 277
CHLOROPHYLL:			
Chlorophyll-a	Fluorometric Corrected		Std. Md. p. 748
HEAVY METALS			
Arsenic	Flameless AA*	0.0002 mg/l	Duluth EPL
	Atomic Absorption (Gaseous Hydride)	0.001 mg/l	EPA p. 95
Cadmium	Atomic Absorption Flameless	0.008 µg/l	Duluth
		0.002 µg/l	Std. Md. p. 210
Chromium	Flameless AA*	0.0003 mg/l	Duluth
	Atomic Absorption	0.001 mg/l	Std. Md. p. 210
			A.S.T.M. p. 351
			EPA p. 105
Copper	Flameless AA*	0.0002 mg/l	Duluth
	Atomic Absorption	0.001 mg/l	Std. Md. p. 210
			A.S.T.M. p. 351
			EPA p. 108
Lead	Flameless AA*	0.0002 mg/l	Duluth
	Atomic Absorption Flameless	0.05 mg/l	EPA p. 112
Mercury	Flameless AA*	0.00002 mg/l	Duluth
	Cold Vapor Method	0.0002 mg/l	A.S.T.M. p. 344
			EPA p. 118
Nickel	Flameless AA*	0.0008 mg/l	Duluth
	Atomic Absorption	0.005 mg/l	A.S.T.M. p. 351
			EPA p. 141
Selenium	Atomic Absorption	0.001 mg/l	EPA p. 145
	Gaseous Hydride	0.002 mg/l	EPA p. 145
Zinc	Flameless AA* and Atomic Absorption	0.0001 mg/l	Duluth
	Atomic Absorption	0.001 mg/l	Std. Md. p. 129
			A.S.T.M. p. 351
			EPA p. 155

*=1975 samples
°=Environmental Research Laboratory - see Poldoski, 1975.

PESTICIDES & ORGANIC CONTAMINANTS:			
DDD	Gas Chromatography	0.001 µg/l	EPA p. 1973
DDE	Gas Chromatography	0.001 µg/l	EPA p. 1973
P-P-DDT	Gas Chromatography	0.001 µg/l	EPA p. 1973
Dieldren	Gas Chromatography	0.001 µg/l	EPA p. 1973
1242 PCB	Gas Chromatography	0.01 µg/l	EPA p. 1973
1254 PCB	Gas Chromatography	0.01 µg/l	EPA p. 1973
1260 PCB	Gas chromatography	0.01 µg/l	EPA p. 1973
DEHP	Gas chromatography	1.0 µg/l	EPA p. 1973
DBP	Gas chromatography	1.0 µg/l	EPA p. 1973

continued

Table 2. (continued)

Group/Variable	Analytical Method	Sensitivity	Reference
RADIOACTIVITY			
Gross Beta	Low background external proportional alpha/beta counter	1 pCI/l	P.H.S 5.2.1.
Zinc 65	Sodiumiodide gamma spectrometer	30 pCi/l	P.H.S. 5.2.1.
Zirconium 95	Sodiumiodide gamma spectrometer	13 pCi/l	P.H.S. 5.2.1.
Niobium 95	Sodiumiodide gamma spectrometer	13 pCi/l	P.H.S. 5.2.1.
Cesium 137	Sodiumiodide gamma spectrometer	15 pCi/l	P.H.S. 5.2.1.
Cobalt 60	Sodiumiodide gamma spectrometer	15 pCi/l	P.H.S. 5.2.1.
Manganese 54	Sodiumiodide gamma spectrometer	13 pCi/l	P.H.S. 5.2.1.
	SEDIMENT VARIABLES		
NUTRIENTS			
Ammonia	Automated phenolate analysis	1 µg/l	Technicon Industrial Method 154-71W
Nitrate	Automated cadmium reduction	10 µg/l	Technicon Industrial Method 100-70W
Total Kjeldahl Nitrogen	1974 automated phenolate analysis sulfuric-perchloric digestion on micro-kjeldahl units	2 µg/l	Technicon Industrial Method 154-71W
	1975 automated phenolate analysis block digestion	2 µg/l	Technicon Industrial Method 154-71W
Total Phosphorus	Ascorbic acid reduction	2 µg/l	Technicon Industrial Method 155-71W
GENERAL			
Total Solids	Moisture determination balance	1 mg/l	Std. Md. p. 91, 14th Ed.
Volitle Solids	Moisture determination balance	1 mg/l	Std. Md. p. 95, 14th Ed.
Chemical Oxygen Demand	Dichromate reflex method	0.2 mg/l	Std. Md. p. 495, 14th Ed. Method 220
HEAVY METALS			
Arsenic	Gaseous hydride	0.001 mg/l	EPA p. 95
Cadmium	Atomic absorption	0.008 mg/l	EPA p. 101
Chromium	Atomic absorption	0.001 mg/l	EPA p. 105
Copper	Atomic absorption	0.001 mg/l	EPA p. 108
Iron	Atomic absorption	0.005 mg/l	EPA p. 110
Lead	Atomic absorption	0.005 mg/l	EPA p. 112
Manganese	Atomic absorption	0.001 mg/l	EPA p. 116
Mercury	Cold vapor method	0.0002 mg/l	ASTM p. 344 EPA p. 118
Nickel	Atomic absorption	0.005 mg/l	EPA p. 141
Selenium	Atomic absorption	0.001 mg/l	EPA p. 145
Zinc	Atomic absorption	0.001 mg/l	EPA p. 155
ORGANIC CONTAMINANTS			
Dieldrin	Gas chromatograph	10 µg/kg	EPA 1973 FED REG. 38
DDT (TOTAL)	Gas Chromatograph	20 µg/kg	EPA 1973 FED. REG. 38
DDD	Gas Chromatograph	20 µg/kg	EPA 1973 FED. REG. 38
DDE	Gas chromatograph	20 µg/kg	EPA 1973 FED. REG. 38
PCB (1242, 1254, 1260)	Gas chromatograph	200 µg/kg	EPA 1973 FED. REG. 38
Dibutylphthalate (DBP)	Gas chromatograph	60 µg/l	EPA, 1973 FED. REG. 38
Diethylhexyl phthalate (DEHP)	Gas chromatograph	90 µg/l	EPA 1973

continued

Table 2. (continued)

FISH PARAMETERS

Group/Variable	Analytical Method	Sensitivity (mg/kg)	Reference
ORGANIC CONTAMINANTS			
Dieldrin	Multiresidue method Gas chromatography	0.01	PAM Vol. 1
Lindane	Multiresidue method Gas chromatography	0.01	PAM Vol. 1
DDT	Multiresidue method Gas chromatography	0.02	PAM Vol. 1
DDE	Multiresidue method Gas chromatography	0.01	PAM Vol. 1
DDD	Multiresidue method Gas chromatography	0.01	PAM Vol. 1
Chlordane	Multiresidue method Gas chromatography	0.04	PAM Vol. 1
Methoxychlor	Multiresidue method Gas chromatography	0.02	PAM Vol. 1
Arochlor (PCB)	Multiresidue method Gas chromatography	0.04	PAM Vol. 1
Polybromated biphenyl (PBB)	Multiresidue method Gas chromatography	0.01	PAM Vol. 1
Benzene hexachloride	Multiresidue method Gas chromatography	0.01	PAM Vol. 1
Hexachlorobenzene	Multiresidue method Gas chromatography	0.01	PAM Vol. 1
Hexachlorobutadeine	Multiresidue method Gas chromatography	0.01	PAM Vol. 1
Dibutylphthalate	Multiresidue method Gas chromatography	0.20	PAM Vol. 1
Diethylexylphthalate	Multiresidue method Gas chromatography	0.50	PAM Vol. 1
HEAVY METALS			
Arsenic	Atomic Absorption	1.0	AOAC Vol. 53, No. 6
Mercury	Mercury Analyzer	0.01	Perkins-Elmers-Coleman
Cadmium	Atomic Absorption	1.0	Bull. Env. Cont. & Tox. Vol. 3
Chromium	Atomic Absorption	1.0	Bull. Env. Cont. & Tox. Vol. 3
Copper	Atomic Absorption	1.0	Bull. Env. Cont. & Tox. Vol 3
Lead	Atomic Absorption	1.0	Bull. Env. Cont. & Tox. Vol. 3
Magnesium	Atomic Absorption	1.0	Bull. Env. Cont. & Tox. Vol. 3
Nickel	Atomic Absorption	1.0	Bull. Env. Cont. & Tox. Vol. 3
Selenium	Atomic Absorption	1.0	Bull. Env. Cont. & Tox. Vol. 3

Table 3. Collection pattern for sampling locations in the nearshore waters, Lakes Superior and Huron, 1974 and 1975

IMPACTED
Station/Sample Depth

Variable Group	1			2			3			4			5			6			7		
	S	M	B +	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
Water																					
In-Situ	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nutrients	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Gen. Chem	*		*	*		*	*		*	*		*	*		*	*		*	*		*
Major Ions	*		*	*		*	*		*	*		*	*		*	*		*	*		*
Heavy Metals	*		*	*		*	*		*	*		*	*		*	*		*	*		*
Pesticides & Org.	*		*	*		*	*		*	*		*	*		*	*		*	*		*
Radionuclides	*																				
Chlorophyll *a*	Composite & 5m grab			Composite & 5m grab			Composite & 5m grab			Composite & 5m grab			Composite & 5m grab			Composite & 5m grab			Composite & 5m grab		
Sediment																					
Nutrients		*			*			*			*			*			*			*	
General		*			*			*			*			*			*			*	
Heavy Metals		*			*			*			*			*			*			*	
Pesticides & Org.		*						*									*				
Biology																					
Bacteria	Surface			Surface			Surface			Surface			Surface			Surface			Surface		
Phytoplankton	Composite & 5m grab						Composite & 5m grab									Composite & 5m grab					
Zooplankton	Bottom haul 15m haul						Bottom haul 15m haul									Bottom haul 15m haul					
Benthos		*			*			*			*			*			*			*	

BACKGROUND
Station/Sample Depth

Variable Group	1			2			3			4			5			6			7		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
Water																					
In-Situ	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nutrients	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Gen. Chem.	*		*				*		*							*		*			
Major Ions	*		*				*		*							*		*			
Heavy Metals	*		*	*		*	*		*	*		*	*		*	*		*	*		*
Pesticides & Org.	*		*				*		*							*		*			
Radionuclides	*																				
Chlorophyll a	Composite & 5m grab						Composite & 5m grab									Composite & 5m grab					
Sediment																					
Nutrients		*						*									*				
General		*						*									*				
Heavy Metals		*						*									*				
Pesticides & Org.		*						*									*				
Biology																					
Bacteria	Surface			Surface			Surface			Surface			Surface			Surface			Surface		
Phytoplankton	Composite & 5m grab						Composite & 5m grab									Composite & 5m grab					
Zooplankton	Bottom haul 15m haul						Bottom haul 15m haul									Bottom haul 15m haul					
Benthos		*			*			*			*			*			*			*	

+ S = surface
M = Mid-depth
B = Bottom
* = indicates sample was collected.

continued

Table 3. (continued)

Collection patterns for all 1975 sampling locations

Variable Group	1			2			3			4			River
	S	M	B †	S	M	B	S	M	B	S	M	B	S
Water													
In-Situ	*	*	*	*	*	*	*	*	*	*	*	*	
Nutrients	*		*	*		*	*		*	*		*	
Gen. Chem.	*		*	*		*	*		*	*		*	
Major Ions	*		*	*		*	*		*	*		*	
Heavy Metals		*									*		*
Pesticides & Org.		*									*		*
Chlorophyll a	5m grab			5m grab			5m grab			5m grab			
Sediment													
Nutrients		*			*			*			*		
General		*			*			*			*		
Heavy Metals		*			*			*			*		
Pesticides & Org.		*			*			*			*		
Biology													
Benthos		*			*			*			*		

† S = surface
M = mid-depth
B = bottom
* = indicates sample was collected

Table 4. Sample collection and preservation method for the nearshore waters, Lakes Superior and Huron, 1974 and 1975

Variable Group	Sample Volume/Container	Sampling Device	Field Preservative	Refrigeration at 4 °C
Water:				
In-Situ	--	Martek MKII	-	
Nutrients	250 ml/disposal plastic	Alpha Bottle (PVC)	10 drops chloroform	x
General CHEM & Major Ions	1 l/disposable plastic	Alpha Bottle (PVC)	none	x
(COD)	125 ml/disposal plastic	Alpha Bottle (PVC)	0.5 ml 1.0N H_2SO_4	x
Chlorophyll-a	250 ml/disposal plastic	Alpha Bottle (PVC)	5 drops $MgCO_3$	x
*Heavy Metals	1 l/disposal plastic	Alpha Bottle (PVC)	10 ml 0.5 N HNO_3	
*Pest. & Org.	4 l/glass	Alpha Bottle (PVC)	100 ml Hexane	
Radionuclides	4 l disposal plastic	Alpha Bottle (PVC)	none	
Sediments:				
Nutrients, General & Metals	250 ml glass jar	Ponar Grab	none	x
Pesticides	4 oz. plastic Whirlpac bag	Ponar Grab	none	x
*Note: 1975 Modifications				
Heavy Metals	1 l	Kemmerer Bottle (PVC) (acid washed)	2 ml HNO_3	x
Pesticides & Org.	38 l filtered through polyurethane plug	Alpha Bottle (PVC)	Hexane	x
Bacteria	125 ml/glass	Alpha Bottle (PVC)	none	x
Phytoplankton	3.79 liter/disposal plastic	Alpha Bottle (PVC)	95% Buffered Formalin + Lugols solution	
Zooplankton	125 ml/plastic	Plankton net	95% Buffered Formalin	
Benthos	1 quart jar/glass	Ponar Grab	95% Buffered Formalin	

In 1975, collections at special river stations (or station 1 when no river was present) and station 4 were made for heavy metals and organic contaminants. An exception to this was Isle Royale where stations 2 and 5 were sampled rather than stations 1 and 4. Additional samples were collected at station 1 at Alpena and Cheboygan. River samples were taken 0.5-m below the surface. All other metals samples were taken at mid-depth. Triplicate water samples for metals analysis were taken at each station with a PVC Kemmerer bottle rinsed with 1:1 nitric acid and deionized water. These samples were analyzed by the National Water Quality Laboratory (NWQL) of the U. S. EPA, in Duluth, according to the method outlined by Poldoski (1974).

In 1975, organic contaminants were analyzed from a 38-liter water sample collected with a PVC Kemmerer sampler. The sample was filtered through a polyurethane foam plug which was rinsed with distilled water, acetone and hexane. The eluate was washed, dried and concentrated before analysis by gas chromatography (Bedford, 1974).

Radioactivity

During 1974, a four-liter water sample was collected at each location at station 1 one-meter below the surface with an alpha bottle. Samples were transported to the Department of Public Health radiological health laboratory and analyzed for gross beta and the gamma emitting radionuclides shown in Table 2.

Sediment Chemistry

During the fall of 1974, sediment samples were collected at 9 locations in Lake Huron and 12 locations in Lake Superior (Table A-7). In 1975, sediments were collected at Calcite and Saginaw Bay in Lake Huron and Marquette Harbor in Lake Superior (Table A-8). All sediments were collected with a Ponar grab sampler, placed in either a 250-ml glass jar (pesticides) or a four ounce plastic whirlpac bag, iced and flown to Lansing's Environmental Protection Bureau Laboratory for analysis. Tables 2, 3 and 4 summarized sediment parameters analyzed, sampling stations, and collection techniques.

Bacteria

Bacteriological samples were collected only during 1974. Replicate samples were collected from the surface at designated stations (Table 3) in sterilized glass bottles. The samples were iced, transported to the Michigan Public Health Laboratory in Lansing and analyzed within 48 hours. Samples were analyzed for total coliforms, fecal coliforms and fecal streptococcus using the membrane filter method (APHA, 1971) with detection levels of 100, 10 and 10 counts/100 ml, respectively.

Phytoplankton

Phytoplankton samples were collected at designated stations (Table 3) during 1974 only. Two types of samples were taken from each site. The first was a grab sample at a depth of 5-m. The second type was a composite sample containing equal volumes of water collected from the water column at 5-m depth intervals, including the surface. Both types of samples were placed in 3.8-liter disposable plastic containers and preserved with formalin and Lugol's solution. The samples were transported to Bowling Green State University, Bowling Green, Ohio, for identification and enumeration under the direction of Dr. Rex Lowe.

One-liter portions of all samples were concentrated by sedimentation and decantation. A 1-ml aliquot of each concentrated sample was analyzed in a Palmer-Maloney nannoplankton counting chamber. At least 500 algal units were counted from each sample, using magnification up to 450x. Algal units consisted of:

Colonial greens and blue-greens	1 colony/unit
filamentous greens and blue-greens	10 cells/unit
all diatoms and chrysophytes	1 cell/unit
all cryptophytes and dinoflagellates	1 cell/unit

Species identifications were made in the nannoplankton chamber or with a wet mount using oil emersion (1000x). Diatoms were identified to species from cleared Hyrax mounts.

Zooplankton

Zooplankton samples were collected only in 1974. Two types of zooplankton samples were collected at designated stations (Table 3) using a 0.5-m diameter, 64-μ mesh plankton net. The first sample type was vertical haul from the bottom and the second was a vertical haul from 15-m, or bottom in depths less than 15-m. Each sample was washed from the cod end of the net into a sample bottle and preserved with formalin. The samples were transported to the University of Wisconsin in Milwaukee, Wisconsin for enumeration and identification under the direction of Dr. Byron Torke. Results were reported as organisms/m^3.

Benthic macroinvertebrates

Triplicate Ponar grab samples were collected at each of the designated stations (Table 3) during the fall of 1974 and the summer of 1975. Each sample was sieved through a U. S. Standard #30 mesh screen and the residue placed in quart jars. The samples were preserved with buffered formalin and transported to Lansing where they were sorted, identified and enumerated. The results were reported as organisms/m^2.

Organic chemicals and heavy metals in fish

Fish were collected in Lake Superior at 12 and 18 locations in 1974 and 1975 respectively and at 5 and 3 locations in Lake Huron during 1974 and 1975 respectively. Whitefish (*Coregonus clupeaformis*), herring (*Coregonus artedii*) and both fat and lean lake trout (*Salvelinus namaycush siscowet* and *Salvelinus namaycush namaycush* respectively) were collected in 1974 in Lake Superior. In 1975, only mottled sculpins (*Cottus bairdi*) were collected in Lake Superior.

Whitefish, rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*) Chinook salmon (*Oncorhynchus tshawytscha*), walleye (*Stizostedion vitreum*) and yellow perch (*Perca flavescens*) were sampled in Lake Huron in 1974. In 1975 only yellow perch were collected in this project. Fish were iced, transported to Lansing, frozen and analyzed by the Michigan Department of Agriculture by methods shown in Table 2. Analyses were performed on skinless fillets of individual fish and in the case of yellow perch, on a composite of four to six fillets. Sculpins were gutted and analyses conducted on a composite of six to thirty fish. Several species of fish were analyzed for dieldrin, DDT, PCB and mercury during 1974 in conjunction with the Great Lakes Environmental Contaminants Survey (GLECS) program. For some species, the Upper Lakes Reference Group (ULRG) of the IJC supported additional analyses for copper, zinc, lead and cadmium and 11 additional organic compounds (Table 2).

In 1975, the ULRG supported only the collection of mottled sculpins in Lake Superior and yellow perch in Lake Huron, most of which were tested for the above contaminants. Additional fish were monitored in the GLECS program in 1975 and succeeding years. The GLECS program began in 1970 with analysis performed by the U.S. FDA or the Michigan Department of Agriculture (MDA) laboratories.

Data Handling

When data were reported below the detection limit, one-half of the detection limit was used in calculation of averages, standard deviations and other statistics. As a result, some values are reported lower than the detection level. This was done to make a "reasonable" estimate of the concentrations of the paramaters. This assumption should not result in large errors since the values below detection level were generally a low percentage of the total number of observations. Values for pH were "averaged" differently than other parameters, using proper arithmetical handling of logarithams (Barth, 1975). In the report the word "significant" indicates that a statistical test has been preformed. All tests were significant at the P = 0.05 probability level.

Althouth the GLECS data were not collected with the forethought toward rigorous trend analyses, they are the best data available concerning Great Lakes fish contaminants. Fish samples were not always collected from the same locations each year, fish age or length and sex were not held constant and sample size was variable. It is therefore difficult to determine whether or nor these samples are truly representative of the entire population. However, the attempt was to describe overall, lake-wide variations in fish contaminants from year-to-year.

Preliminary examination of the 1974 through 1978 GLECS data indicated that the concentrations of these fish contaminants were not normally distributed and therefore would not meet the assumptions of the analysis of variance test. Using Taylor's power law, the transformation determined was to replace each X value with $X^{-0.03355}$. The transformed data were tested at the 0.05 alpha level by one-way analysis of variance with tests conducted for both year-to-year and location differences. The Student-Newman-Keuls procedure was used to determine the order of difference when significance was found.

SECTION V

LAKE SUPERIOR

Introduction

Lake Superior is the largest freshwater lake in North America and one of the largest lakes in the world. It is 82,413 km^2 in surface area, approximately 563 km long, 258 km wide, has a maximum depth of 406-m, and a volume of 13,500 km^3. It is the uppermost lake in the Great Lakes system and overlies the relatively insoluble Canadian Shield. The relative insolubility of this geological formation results in low average total alkalinity (43.5 mg/l) and calcium concentrations (14.4 mg/l) in Lake Superior, both less than half of Lake Michigan's averages (Schelske and Roth, 1973).

Historically, there has been little change in the water quality of Lake Superior based on data collected as early as 1907 (Dole, 1909). Total dissolved solids, chlorides and sulfates have remained relatively constant since the early 1900's (Beeton, 1965). Lake Superior is an oligotrophic lake as indicated by non-depletion of nitrate and silica in the summer surface waters and relatively low total phosphorus concentrations at the surface (Schelske et al., 1972). The lake is dominated by oligotrophic species of phytoplankton, zooplankton, benthic macroinvertebrates and fish.

Major currents in Lake Superior have been characterized by a number of investigators (Yeshe et al., 1972, Adams 1970, Murty and Rao 1970). The overall water movement in Lake Superior is counter-clockwise around the periphery of the basin (Figure 3). Contrasting this general movement is a clockwise current around Isle Royale (Adams, 1970). Current velocities in the lake range from a few cm/sec to over 50 cm/sec for the coastal current off the Keweenaw Peninsula.

Physical and General Water Chemistry

Little physical variation occurred in Lake Superior nearshore waters throughout the 1974 survey. Mean location temperatures ranged from 6.6° to 10.0°C during the spring (June) except at Isle Royale, which averaged 3.3°C. Fall mean location temperatures ranged from 13.5° to 22°C, approximately 7.5 °C higher than corresponding spring values. During 1975, for samples collected from the first of June through mid-July, mean temperatures ranged from 4.5°C at Isle Royale to 11.3°C at Grand Marais. River-lake interface station temperatures were generally 6° to 8°C warmer than the lake. Although temperatures varied with depth, no stable thermal stratification was noted.

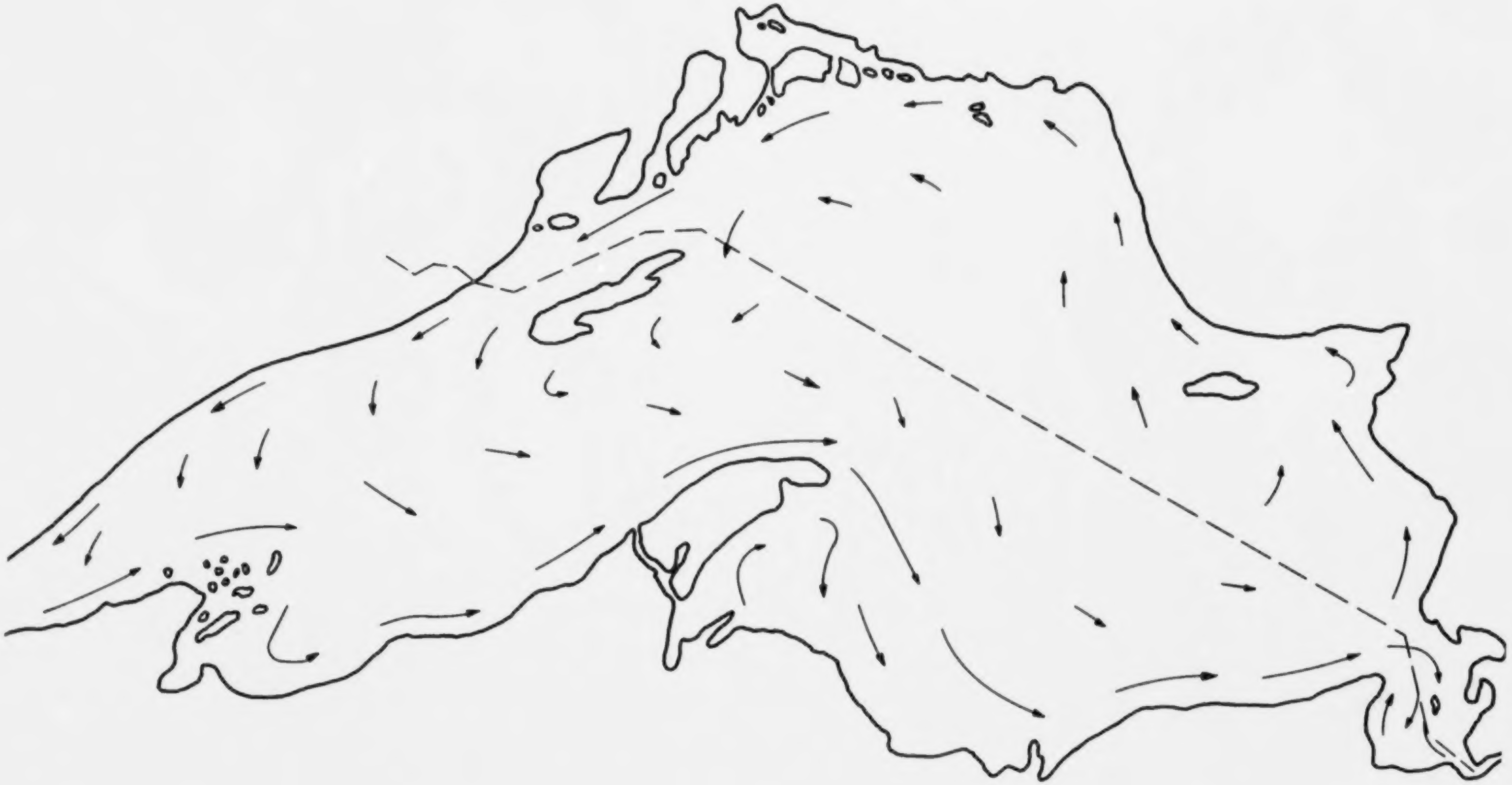


Figure 3 Typical summer surface currents in Lake Superior. (after IJC 1977)

Mean dissolved oxygen (DO) concentrations at individual locations during 1974 ranged from 10.1 to 13.2 mg/liter during spring. The higher temperatures recorded during the fall sampling period may have been the cause of lower DO levels which ranged from 8.5 to 10.9 mg/l. In 1975, mean dissolved oxygen concentrations ranged from 11.2 to 13.2 mg/l, with a lakewide mean of 12.4 ± 0.6 mg/l. Dissolved oxygen concentrations were near saturation levels at all locations and depth profiles were orthograde.

In 1974, mean hydrogen ion concentrations (pH) at individual locations ranged from 7.4 to 8.0 pH units during the spring and from 7.6 to 7.9 during the fall. Mean spring and fall pH values were nearly identical to the lakewide mean of 7.7. In 1974, no significant differences were evident between sampling periods, locations or depths. In 1975, mean pH values ranged from 7.6 near Grand Marais and Isle Royale, to 7.8 at Marquette Harbor. Because equipment failure prevented accurate pH measurements at several locations in 1975, pH was not included in the correlations or other statistical analysis.

Total dissolved solids (TDS) did not vary significantly during 1974. Location means ranged from 52 to 55 mg/l, with a lakewide mean of 53 ± 1 mg/l. No sampling period differences or location differences were evident, although TDS was significantly correlated with nutrients, conductivity and major ions. In 1975, mean TDS values ranged from 55 to 60 mg/l, with a lakewide mean of 57 ± 2 mg/l. TDS values from both years were similar to Beeton's (1965) suggested long-term average value of approximately 60 mg/l, indicating that the lake's water quality as indicated by this parameter has remained relatively constant since the early 1900's.

Mean location conductivity measurements in Lake Superior ranged from 85 to 88 µmhos/cm during spring sampling, and from 83 to 92 µmhos/cm in the fall of 1974. The lakewide mean was 88 ± 1 µmhos/cm. Conductivity measurements varied little with depth, and no significant sampling period or location differences were found. During 1975, mean location conductivity measurements ranged from 85 to 101 µmhos/cm with a lakewide mean of 88 ± 5 µmhos/cm. The location values were relatively constant with the exception of the Carp River at Marquette which was 13 µmhos/cm above the lakewide mean reflecting the impact of the river.

Chloride and sulfate mean location concentrations were low throughout 1974, ranging from 0.9 to 1.4 mg/l and 2.5 to 3.2 mg/l, respectively. No significant depth, location, or sampling period differences were noted for these constituents. Mean location concentrations of chlorides and sulfates were similar during 1975, ranging from 1.1 to 2.3 mg/l and 2.9 to 4.7 mg/l, respectively. These values agree with the mean Lake Superior values reported by Beeton and Chandler (1963), of 1.9 mg/l for chloride and 3.2 mg/l for sulfate. Apparently, little change has occurred in the concentration of these constituents in Lake Superior over the last decade. While chlorides and sulfates were most closely correlated to TDS, they also correlated well with nutrients and the conservative ions.

Nutrients and Chlorophyll *a*

Mean annual nitrate (NO_3-N) concentrations in 1974 ranged from 0.239 mg/l at Carp River (Marquette) to 0.326 mg/l near Big Bay, with a lakewide mean of 0.269 ± 0.021 mg/l. The mean fall NO_3-N concentration (0.277 ± 0.027 mg/l) was significantly higher than the mean spring concentration (0.261 ± 0.018 mg/l). Since nitrate concentrations generally are reduced through phytoplankton growth in the late summer. This apparent reversal suggests that changes have occurred in the fall samples following collections due to improper preservation techniques or contamination. Total nitrogen concentrations were relatively constant throughout the year, although organic nitrogen values decreased in most of the fall samples relative to spring values. Along with this decrease in organic nitrogen, NO_3-N and NH_3-N increased in these same samples, indicating some degradation of the organic nitrogen to NO_3-N and NH_3-N before analysis suggesting improper preservation techniques. In the fall, concentrations of NO_3-N were significantly lower at the surface than at the bottom probably due to phytoplankton utilization.

Mean nitrate (NO_3-N) concentrations in 1974 were low with no significant differences between locations, sampling periods or depths. Location means ranged from 0.001 to 0.002 mg/l with a lakewide mean of 0.002 ± 0.002 mg/l. Three percent of the values were below the detection limit (0.001 mg/l) with all nondetectable values occurring in the spring.

In 1975, NO_3-N and NO_2-N were analyzed together. The lakewide mean was 0.27 ± 0.03 mg/l, nearly identical to the 1974 results. Location means ranged from 0.22 mg/l at Tahquamenon River to 0.31 mg/l at Upper Portage Entry.

Mean ammonia (NH_3-N) concentrations were low at all locations in 1974, ranging from 0.001 to 0.014 mg/l, with a lakewide mean of 0.005 ± 0.002 mg/l. Fourteen percent of the values were below the detection limit (0.002 mg/l. Maximum NH_3-N levels were recorded at station 1 off the Carp River (0.41 mg/l) but these relatively high levels were not present at stations further offshore. The Carp River receives primary treated municipal wastewater from the Marquette municipal wastewater treatment plant. Previous studies (MWRC 1969a, MWRC 1973) revealed water quality degradation downstream of the Marquette wastewater treatment plant in the Carp River and in the nearshore waters of Lake Superior. Ammonia concentration in Lake Superior was strongly correlated with the conservative ions, phosphorus and hardness, and negatively correlated with dissolved oxygen (Table A-4).

In 1975, a similar percentage of NH_3-N readings was below the detection limit. The lakewide mean was 0.002 ± 0.001 mg/l excluding the Carp River location (0.015 ± 0.021 mg/l) which, as in 1974, was substantially higher than other locations.

In 1974, mean total nitrogen (total-N) concentrations at individual locations ranged from 0.36 to 0.46 mg/l with a lakewide mean of 0.40 ± 0.003 mg/l total-N. Big Bay had the highest mean total-N concentration during both samplings in 1974. The 1975 lakewide mean was 0.37 ± 0.04 mg/l with individual location means ranging from 0.30 to 0.45 mg/l. The highest mean value was found at the Carp River, Marquette. No significant differences were found among locations or sampling periods in 1974 or 1975. Total-N was strongly correlated with NO_3 and organic-N (Table A-4).

Mean total orthophosphate concentrations were low at all locations in 1974, ranging from 0.001 to 0.003 mg/l, with 59 percent of the values below the detection limit of 0.002 mg/l. The lakewide mean was 0.002 ± 0.001 mg/l. Fall concentrations were slightly higher than spring levels but differences between sampling periods were not statistically significant. Orthophosphate was correlated with all nutrients, reactive silica and the conservative ions (Table A-4).

In 1975 orthophosphate concentrations were also low, with location means ranging from below detection (<0.001 mg/l) to 0.005 mg/l, excluding the Carp River location which was substantially higher (0.037 ± 0.068 mg/l) than other locations. The lakewide mean excluding Carp River data was 0.001 ± 0.001 mg/l.

In 1974, location means for total phosphorus (total-P) ranged from below the detection level (0.002) to 0.012 mg/l with a lakewide mean of 0.007 ± 0.003 mg/l. Eighteen percent of the values were below the limit of detection (0.002 mg/l). No significant differences were found between locations or sampling periods, even though individual stations at Black River and Carp River had total-P concentrations considerably higher than the lakewide mean (0.020 and 0.150 mg/l, respectively). Both rivers receive municipal wastewater discharges which might explain these elevated total-P values. Unpublished 1973-1974 data from Michigan Water Resources Commission (MWRC, 1975) show total-P levels near the mouth of the Black River averaging approximately 0.04 mg/l. High levels of total-P (0.400 mg/l) were also found near the mouth of the Carp River in 1972 (MWRC, 1973). Correlations of total phosphorus with other parameters were similar to those for orthophosphate.

In 1975, location total-phosphorus means ranged from below the detection level (0.002 mg/l) at Tahquamenon River to 0.015 mg/l at Ontonagon, with a lakewide mean of 0.005 ± 0.003 mg/l excluding Carp River data, and 0.008 ± 0.118 mg/l including Carp River data. The Carp River location mean for total-P was 0.059 ± 0.109 mg/l, reflecting the inputs from the wastewater treatment plant.

In 1974, mean dissolved silica concentrations ranged from 2.0 to 2.8 mg/l, with a lakewide mean of 2.4 ± 0.2 mg/l. Differences between surface and bottom concentrations were not significant, nor were differences between locations. Fall concentrations were significantly lower than those taken in the spring, probably reflecting utilization by diatomaceous phytoplankton. Silica concentrations were positively correlated at a low level with nutrients (except nitrate) and conservative ions and negatively correlated with temperature and nitrates (Table A-4).

In 1975, dissolved silica location means ranged from 2.0 to 2.5 mg/l, with a lakewide mean of 2.2 ± 0.2 mg/l. All concentrations during both years were well above limiting levels for diatomaceous phytoplankton production (Schelske and Roth, 1973).

In 1974, Lake Superior mean chlorophyll a concentrations ranged from 1.09 to 2.27 μg/l, with a lakewide mean of 1.55 ± 0.36 μg/l. No significant differences were found between locations or sampling periods. These concentrations are similar to levels obtained by Schelske and Roth (1973). They found chlorophyll a concentrations usually less than 0.5 μg/l in the open lake, but in bay areas values ranged from 1.2 to 1.7 μg/l, about two or three times those in open waters. No correlations were found between chlorophyll a and other parameters.

In 1975, chlorophyll a values were slightly higher. Means ranged from 1.49 μg/l at Isle Royale to 4.63 μg/l at Carp River (Marquette) but no significant differences were found between locations. The lakewide average was 2.70 ± 1.10 μg/l with Carp River values included, and 2.40 ± 0.83 μg/l without them.

Heavy Metals in Water

Heavy metals concentrations in Lake Superior were generally very low and frequently were below detection. Total selenium concentrations were below the detection level (1.0 μg/l) at all locations in 1974, and in 1975 no selenium analyses were made.

Total mercury was below the 1974 detection level (0.2 μg/l) at all locations. In 1975, total mercury concentrations were also below the detection level (0.02 μg/l) except at Grand Marais (<0.03 μg/l) and Whitefish Bay (<0.04 μg/l), both within the 0.05 μg/l criterion for protection of aquatic life (U. S. EPA 1976).

In 1974, total cadmium was below detection level (2.0 μg/l) at all locations. In 1975, total cadmium detection level was lowered to 0.02 μg/l. The 1978 Great Lakes Water Quality (GLWQA) has an objective for total cadmium in unfiltered samples of 0.2 μg/l to protect aquatic life (GLWQA, 1978). All locations except Big Bay (0.23 μg/l) and Grand Marais (0.48 μg/l in the unfiltered and 0.32 μg/l in the filtered samples) met this criterion. Poldoski (1975) suggested that the variability of the Grand Marais sample was probably due to steps prior to analysis but the real cause of this cadmium concentration is unexplained.

In 1974, total nickel was above the detection level (5 μg/l) only at Big Bay (7 μg/l) and Black River (6 to 9 μg/l). In 1975, the detection level was lowered to 0.8 μg/l, with 64 percent of the samples below detection. Individual samples ranged up to 0.9 μg/l, with all values well below all water quality criteria.

Total lead was found above the 5 μg/l detection level at only three locations in 1974. Presque Isle and Munising were below and Grand Marais equalled the 10 μg/l total lead criterion for Lake Superior for aquatic life (GLWQA, 1978). In 1975, the detection level for total lead was lowered to 0.2 μg/l. Location mean concentrations in 1975 were 0.8 μg/l or less, with a lakewide mean of 0.4 ± 0.2 μg/l. The highest values occurred at Grand Marais but all detectable concentrations were less than 1/10 of the GLWQA (1978) objectives.

Total arsenic concentrations in Lake Superior were below the detection level (1 μg/l) at all locations in 1974. In 1975, the total arsenic detection level was lowered to 0.2 μg/l. Location means in 1975 ranged up to 1.0 μg/l, with a lakewide mean of 0.78 ± 0.2 μg/l. All detectable values were well below the 50 μg/l criterion for public water supply (U. S. EPA 1976).

Althouth total manganese concentrations were consistently detectable during 1974, they were very low, ranging from below the 1 μg/l detection limit at Big Bay to 3 μg/l at Black River, Ontonagon and Carp River. In 1975, the total manganese detection level was reduced to 0.05 μg/l, with mean concentrations ranging from 0.3 to 1.1 μg/l. All values were well below the 50 μg/l criterion for public water supply (U. S. EPA 1976).

Total chromium detection level in 1974 was 1.0 μg/l, with the majority of values below the concentration. All 1974 location means were 1 μg/l or less but individual station concentrations at Grand Marais and Eagle Harbor ranged to 3 μg/l. In 1975, the total chromium detection level was reduced to 0.3 μg/l, with most values at or near this concentration. The 1975 total chromium lakewide mean was 0.42 ± 0.26 μg/l, with Big Bay having the highest mean concentration (1.3 μg/l). All detectable values were well below the 50 μg/l total chromium criterion for public water supply (U. S. EPA 1976) and the Michigan hexavalent chromium Water Quality Standard for aquatic life (25 μg/l) (MWRC, 1978).

Mean total iron concentrations ranged from 18 to 64 μg/l in 1974. Only at Big Bay (330 μg/l) and Munising (320 μg/l) did individual values exceed the drinking water criterion for public water supplies (EPA 1976). The detection level for iron in 1975 was 0.4 μg/l, with location means ranging from 5 to 81 μg/l, and a lakewide mean of 21 ± 23 μg/l. All values were well below the water quality criterion of 300 μg/l for aquatic life protection (U. S. EPA 1976).

In 1974, location means for copper ranged from 3 μg/l at several locations to 8 μg/l at Lower Portage Entry. While differences between location means were not significant, fall values were significantly lower than spring values. The annual location means for copper exceeded the Great Lakes Water Quality Agreement of 5 μg/l for aquatic life (GLWQA 1978) at Lower Portage Entry (8 μg/l), Eagle Harbor (6 μg/l) and Big Bay (6 μg/l). These concentrations probably do not reflect unnatural inputs due to natural copper deposits in these areas. The 1975 copper concentrations were comparable to the fall concentrations of 1974. Location means in 1975 ranged from 1.0 to 2.6 μg/l, with a lakewide mean of 1.5 ± 0.4 μg/l. No copper values in 1975 exceeded the GLWQA objective of 5 μg/l (GLWQA 1978).

In 1974, mean zinc concentrations ranged from 4 μg/l at Upper Portage Entry to 11 μg/l at Big Bay, with a lakewide mean of 8 ± 2 μg/l. All values were well within the GLWOA objective of 30 μg/l (GLWQA 1978). No significant differences were found between locations, but fall values were significantly higher than spring values. Several elevated zinc concentrations were observed in the water samples collected near the bottom which may have been contaminated with sediments. The zinc detection level in 1975 was 0.1 μg/l. Location means ranged from 1.0 to 2.7 μg/l, with a lakewide mean of 2.0 ± 0.9 μg/l. No 1975 zinc values exceeded the above objectives.

Organic Chemicals in Water

In 1974, water samples were analyzed for dieldrin, polychlorinated biphenyls (PCB), and several other organic chemicals (Table 2). In this study, PCB's are reported as total PCB's which is the sum of the three major forms, Arochlor 1242, Arochlor 1254 and Arochlor 1260. Also within this report the total DDT analogs are reported as DDT or total DDT which is a summation of ortho para (o.p.), and para para (p.p.) DDT and their metabolites DDD and DDE. No PCB, dibutylphthalate (DBP), or dieldrin were found above the detection level of 0.01, 1.0, and 0.001 μg/l, respectively. Diethylhexalphthalate (DEHP) was detected at one station at Carp River (Marquette) (3.8 μg/l). No source could be determined although DEHP is used in many products, including some farm chemicals and orchard spray.

DDT and DDE were found only above detection levels (0.001 μg/l) in individual samples from Eagle Harbor (0.004 μg/l), Big Bay (0.002 μg/l), Presque Isle (0.002 μg/l) and Carp River (Marquette) (0.002 μg/l).

In 1975, a more sensitive analytical method developed by Musty (1974) was used for organic chemicals. In this method. two and one half liters of water were filtered through a foam plug and the filtrate-plug extracted with hexane. Interference occurred from the foam plug and/or other sources. As a result, the various organic chemicals in the water and the interfering substance could not be differentiated. Consequently, all values for 1975 were reported as below the level of detection.

Radioactivity

Samples for radioactivity analysis were collected only in the spring and fall of 1974. Zinc 65, zirconium 95, niobium 95, cesium 137, cobalt 60 and manganese 54 were all below the minimum detectable activity (MDA) levels 30, 13, 13, 15, 15 and 13 pCi/l respectively. Correspondingly low gross beta activities also occurred ranging from below the MDA to 5 pCi/l. The lakewide average was 2.0 pCi/l.

Sediment Chemistry

In 1974 and 1975, most sediments from the nearshore waters of Lake Superior had very low levels of pesticides, polychlorinated biphenyls (PCB), metals, nutrients and chemical oxygen demand (COD).

Arochlor 1242, 1254 and 1260, p.p. DDT, o.p. DDT, and DDD were below the detection level of 3 μg/kg at all locations with the exception of DDD at one station in Munising Bay in 1974. Dieldrin and DDE were below the detection level of 1 μg/kg at all locations.

Dibutylphthalate (DBP) was detected in the sediment from all Lake Superior locations except Isle Royale in concentrations ranging from less than 60 to 540 μg/kg. Concentrations of diethylhexalphthalate (DEHP) in sediment ranged from below detection (90 μg/kg) at Black River and Isle Royale to an average of 4994 ± 6855 μg/kg at Munising.

A 1974 wastewater survey indicated the Kimberly Clark paper company was discharging 2.3 μg/l DEHP from its facility and is the only known source of phthalates in Munising sediments. However, phthalates, which are plasticizers, are widely used in many industrial processes and are found in numerous house-hold products.

Hexane extractable oil and grease concentrations in sediments exceeded U.S. EPA dredge spoil criteria at Munising (16,804 ± 24,867 mg/kg), Upper Portage Entry (5400 ± 0.0 mg/kg) and Whitefish Point (6000 ± 3997 mg/kg). Elevated concentrations of hexane extractables in the Munising sediments probably are the result of the past sulfite-pulp paper process at Kimberly Clark. This process was utilized prior to the Company's conversion to specialty paper products. Upper Portage Entry sediments were probably contaminated by mining wastes or discharges from ship traffic through this passage. The source of the oil and grease in the sediments at Whitefish Point (one station) is unknown.

Concentrations of nickel in sediments exceeded the dredge spoil criterion at Ontonagon, Upper Portage Entry, Eagle Harbor, Isle Royale, Presque Isle and Munising.

Copper exceeded the dredge spoil criterion at Upper Portage Entry, Eagle Harbor and Munising. Copper and nickel in the sediments at Upper Portage Entry were probably the result of past mining activities and natural ores in the bedrock and glacial till.

Concentrations of manganese exceeded the dredge spoil criterion at Isle Royale and Presque Isle.

Total chromium exceeded the dredge spoil criterion only at Presque Isle.

Levels of lead, zinc, arsenic, and volatile solids exceeded dredge spoil criteria only at Munising.

Concentrations of total phosphorus, TKN, and COD were elevated at Munising, Ontonagon and Carp River. This probably was due to organic enrichment from wood processing and paper mill plants as well as wastewater from municipalities.

The principal sources of degradation at Munising were wood fibers previously deposited from the Kimberly Clark pulp mill (MWRC, 1969), several other now-defunct saw mills and pulping operations, storm sewers and the Munising wastewater treatment plant effluent discharged to the Anna River. Woody material was still evident in the sediment samples collected in 1974, even though the pulp mill stopped operation and the company's paper mill discharges were greatly reduced in 1962. Cellulose fibers are relatively inert and may cover the sediments for many years, as evidenced by samples collected at other locations in the Great Lakes.

Bacteria

Densities of total and fecal coliforms and fecal streptococci have been used to indicate pollution because these organisms are associated with the feces of warmblooded animals. Total coliform concentrations, however, vary as a result of inputs from several sources, and thus may not reflect human degradation of water quality. Prior to Rao and Henderson's (1974) baseline bacteriological survey of Lake Superior, bacteriological data were limited to miscellaneous nearshore studies for permit enforcement and public health concerns.

Samples taken in 1974 from Michigan's nearshore Lake Superior waters generally had low bacterial densities, reflecting high water quality. A total of 106 water samples were analyzed with 69, 90 and 90 percent, respectively, of the total coliform, fecal coliform and fecal streptococci counts below detection levels (100, 10 and 10 organisms/100 ml).

Total coliforms were elevated at the nearshore stations in the spring at Munising and Presque Isle, and in the fall at Black River, Ontonagon, Carp River and Munising (Table 5).

The maximum fecal coliform value observed, 17,138 organisms/100 ml at Carp River, exceeded the Michigan water quality standard of 200 organisms/100 ml (MWRC, 1977). This high value probably resulted from the wastewater treatment plant discharge from Marquette.

Fecal streptococci values were consistently below detection levels in both spring and fall, except for Carp River and moderate spring levels at Munising. At Carp River, station 1 had high levels of fecal streptococci, reflecting discharges from the Marquette wastewater treatment plant.

Phytoplankton

Historical information on the phytoplankton of Lake Superior is limited and usually restricted to studies of net plankton. Holland (1965) found an oligotrophic diatom assemblage in 1964 dominated by small forms of *Cyclotella* (*C. glomerata*, *C. Stelligera*, *C. ocellata*, and *C. kutzingiana*). Schelske *et al*. (1972) in both nearshore and offshore samples reported a dominance of diatoms, especially of the genus *Cyclotella*. Other common diatoms (*Asterionella*, *Tabellaria* and *Synedra*) were reported by Schelske and Roth (1973). *Dinobryon* and *Fragilaria* have also been often reported (Davis, 1966). Lake Superior was classed as oligotrophic based on phytoplankton in a review by Vollenweider, *et al*. (1974).

The nearshore waters of Lake Superior were sampled for phytoplankton in June and August through September, 1974. Diatoms were the dominant algal group at all locations in June, averaging 57 percent by abundance. In June, dominant species at all 12 locations were *Asterionella formosa*, four species of *Cyclotella* (*C. compta*, *C. glomerata*, *C. kutzingiana* and *C. ocellata*), *Rhodomonas minuta*, *Synedea tenera*, and *Melosira granulata* (Table A-9).

Table 5. Geometric mean bacterial densities in nearshore Lake Superior, 1974.
(Expressed as organisms/100 ml)

Location	Station	Total Coliform		Fecal Coliform		Fecal Streptococci	
		Spring	Fall	Spring	Fall	Spring	Fall
Black River*	1	< 100	1,500	< 10	14	< 10	< 10
	3	< 100	424	< 10	< 10	< 10	< 10
	6	< 100	< 100	< 10	< 10	< 10	< 10
Ontonagon	1		346		< 10		< 10
	2	< 100	2,956	< 10	59	< 10	< 10
	3	< 100	346	< 10	49	< 10	< 10
	4	< 100	3,600	< 10	312	< 10	< 10
	5	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	< 100	< 10	< 10	< 10	< 10
	7	< 100	< 100	< 10	< 10	< 10	< 10
Upper Portage Entry	1	< 100	< 100	< 10	< 10	< 10	< 10
	2	< 100	< 100	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	4	< 100	< 100	< 10	< 10	< 10	< 10
Lower Portage Entry	1	282	141	< 10	< 10	< 10	< 10
	2	< 100	< 100	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	4	141	< 100	< 10	< 10	< 10	< 10
Eagle Harbor*	1	< 100	< 100	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
Isle Royale	1	141	< 100	< 10	< 10	< 10	< 10
	2	200		< 10		< 10	
	3	< 100	< 100	< 10	< 10	< 10	< 10
	4	< 100	< 100	< 10	< 10	< 10	< 10
Big Bay*	1	< 100	< 100	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	245	< 10	< 10	< 10	< 10
Presque Isle	1	173	< 100	< 10	< 10	< 10	< 10
	2	282	< 100	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	4	346	< 100	< 10	< 10	< 10	< 10
	5	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	< 100	< 10	< 10	< 10	< 10
	7	< 100	< 100	< 10	< 10	< 10	< 10

continued

Table 5. (continued)

Location	Station	Total Coliform		Fecal Coliform		Fecal Streptococci	
		Spring	Fall	Spring	Fall	Spring	Fall
Carp River	1	< 100	1,496,262	< 10	17,138	< 10	3,369
	2	< 100	692	< 10	22	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	4	< 100	141	< 10	< 10	< 10	< 10
	5	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	< 100	< 10	< 10	< 10	< 10
	7	< 100	< 100	< 10	< 10	< 10	< 10
Munising	1	3,980	282	46	< 10	341	< 10
	2	282	< 100	< 10	< 10	20	< 10
	3	748	< 100	49	< 10	59	< 10
	4	< 100	141	< 10	< 10	< 10	< 10
	5	775	141	26	< 10	60	< 10
	6	200	812	28	< 10	14	< 10
	7	141	1,039	< 10	< 10	14	< 10
Grand Marais*	1	< 100	< 100	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	141	< 10	< 10	< 10	< 10
Whitefish Point*	1	< 100	141	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	141	< 10	< 10	< 10	< 10

*Background Location

In late August and September, the numerical dominance of diatoms was reduced to 29 percent from the spring value of 57 percent. Although present at relatively low numbers, diatoms still were slightly more abundant than other classes (Table A-10). This change was due primarily to an increase in *Dinobryon* which shifted the Chrysophyta from 5 percent in the spring to 22 percent in the fall. The Cryptophyta increased from 15 to 21 percent in the fall, while blue-greens and greens remained about the same. Fewer dominant species were found than in the spring. In the fall, *Rhodomous minuta* and *Dinobryon* ranked first and second in numbers at eight locations. Other dominant species included *Fragilaria crotonensis*, *Cyclotella compta*, *C. Glomerata*, *Asterionella formosa* and *Oscillatoria prolifica* which was especially abundant in Whitefish Bay.

Mean values for total algal numbers in the spring ranged from 338 units/ml at Isle Royale to 2214 units/ml at Carp River. Fall means ranged from 533 units/ml at Whitefish Bay to 4587 units/ml at Eagle Harbor. Statistical comparisons between composite samples and 5-m grab samples showed no significant differences between number of species or number of algal units collected. The lakewide mean algal abundance and number of species was 1655 ± 628 units/ml and 28 ± 6 species in the 5-m grab sample and 1689 ± 831 units/ml and 30 + 6 species in the composite samples (Figure 4).

Variations in the algal community were found for individual stations within each location. This was expected since stations at a particular location included river-mouth stations, relatively shallow lake stations and lake stations located up to 3.2 km offshore in 30-m of water. Although variations in species composition were present, generally the abundant species at a location were found at all stations within that location. However, this trend was not consistent at two locations. Blue-green algae were abundant in the shallow South Bay stations at Munising but not further offshore. In the spring, *Dactylococcopsis fascicularis*, were abundant at station 1, near the Anna River mouth, but it was succeeded by *Oscillatoria prolifica* in the fall. At Carp River, large numbers of *Stephanodiscus invisitatus*, a common eutrophic river plankton (Lowe 1974), were found only near the river mouth. The other algae abundant at this station, however, were also present at the other stations.

Rhodomonas minuta was one of the two most abundant forms found during the spring at all locations except Lower Portage Entry, Eagle Harbor, Isle Royale and Grand Marais. In the fall *R. minuta* was very abundant at all locations except Isle Royale and Whitefish Bay. Mean *R. minuta* percentages ranged from 0 to 34 percent in the spring and 6 to 38 percent in the fall. Isle Royale was the only location where *R. minuta* did not comprise at least 10 percent of the total algal numbers during both sample periods.

Dinobryon was the most abundant chrysophyte found and one of the two most abundant algae in the fall samples.

Several species of blue-green algae were present in most samples but were found in abundance only at Munising and Whitefish Bay.

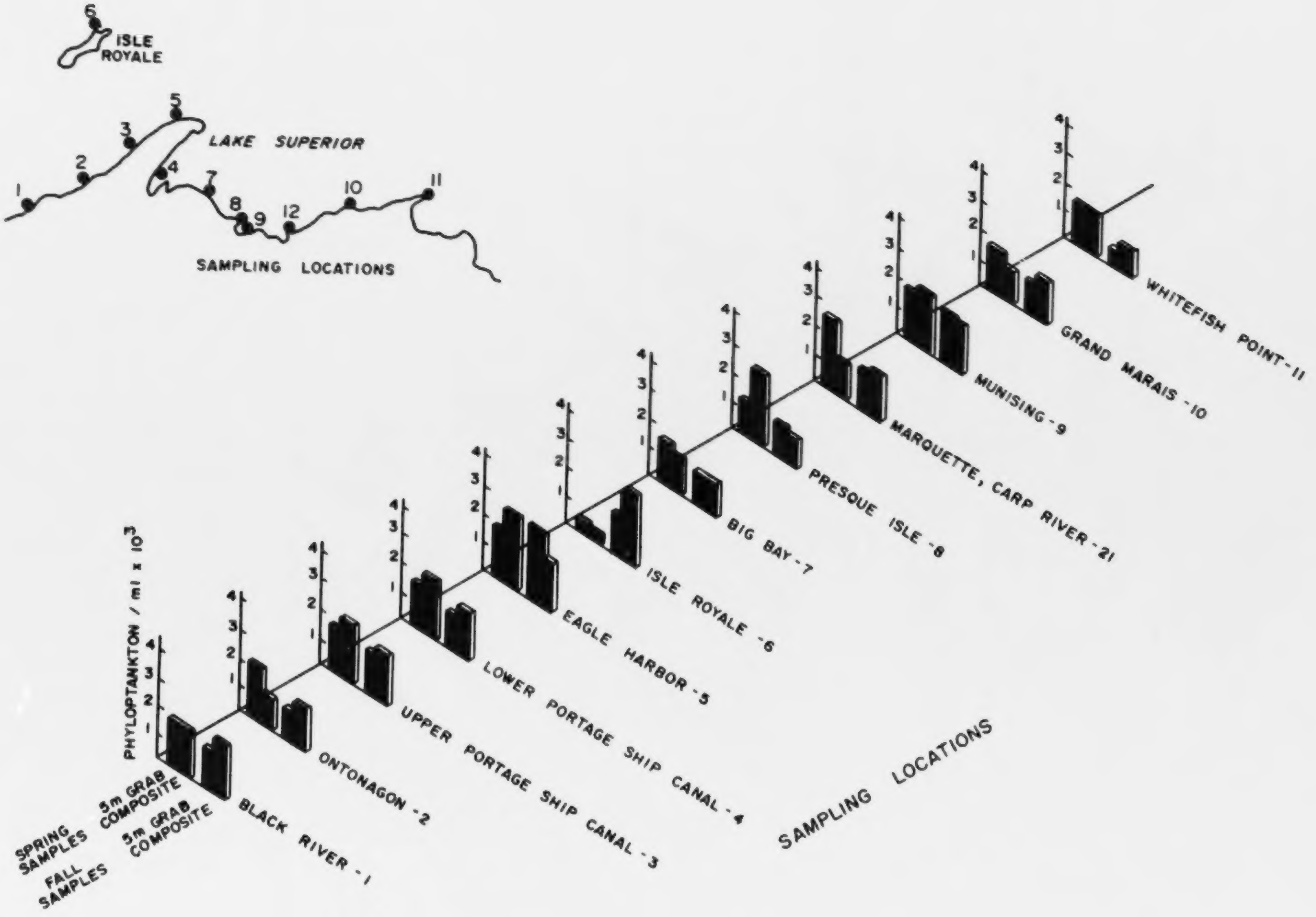


Figure 4 Nearshore phyloptankton standing crop, Lake Superior, 1974

Chlamydomonas globosa, a green alga, was the second most abundant species at Eagle Harbor in the spring.

Zooplankton

The crustacean zooplankton of Lake Superior are generally dominated by diaptomids (Diaptomus sicilis and D. ashlandi) the cyclopoid Cyclops bicuspidatus thomasi, and the cladoceran Bosmina longirostris (Patalas, 1972). Schelske and Roth (1973) found that Diaptomus and Limnocalanus dominated the zooplankton with Cyclops and Senecella often present but in lower numbers. They found total zooplankton densities ranging from 1200 to 16,000 organisms/m^3, with an average of approximately 4600 organisms/m^3. Selgeby (1975) described the seasonal variation and abundance of crustacean zooplankton in Lake Superior during 1971 and 1972. He found C. bicuspidatus thomasi, D. ashlandi, D. silicis, L. macrurus and Senecella present throughout the year.

Rotifers of Lake Superior were reviewed by Watson (1974) and studied by Nauwerck (1972) who collected about 20 taxa during the summer and autumn of 1970. Kellicottia longispina, Conochilus unicornis and Polyarthra vulgaris were the most common species with Gastropus stylifer, Collotheca mutabillis, and Conochiloides dossuarius also often found. Nauwerck suggested the following trophic classifications: Kelicottia, Notholca, and Synchaeta are generally coldwater oligotrophic genera; Conochilus, Collotheca, and Gastropus are warmwater oligotrophic genera; Polyarthra and Asplanchna are mestrophic genera; and Brachionus, Filinia and Keratella are coldwater eutrophic genera.

The most common crustacean zooplankton in 1974 were the cladoceran, Bosmina longirostris, the calanoid copepods, Diaptomus oregonensis and D. minutus, and the cyclopoid copepod Cyclops bicuspidatus thomasi. In the fall, three additional species were abundant: the cladocerans, Holopedium gibberum and Daphnia retrocurva, and the calanoid copepod Epischura lacustris. In the spring Diaptomus sicilis was also commonly found (Table A-11).

During 1974, mean numbers of crustacean zooplankton ranged from 859/m^3 at Isle Royale in June to 7874/m^3 at Carp River in the fall, with a lakewide mean of 2270 /m^3 (Table A-12). About 40 percent of those collected were nauplii, 10 percent unidentified cyclopoid copepods and 15 percent unidentified diaptomid copepods.

Senecella calanoides and Limnocalanus macrurus are two oligotrophic relic species found in 1974. S. calanoides was found in low numbers (one to nine organisms/m^3) during both sampling periods at Isle Royale, and in the spring at Carp River and Whitefish Point. L. macrurus was found at 8 of 12 locations, ranging from one to nine organisms/m^3. It occurred during both sampling periods at Eagle Harbor, Big Bay and Grand Marais. The abundance of L. macrurus is probably under-estimated since it generally occurs below 50-m depths (Patalas 1972, Conway, 1977) which were not sampled in this study. It was not abundant in the nearshore areas sampled and, when found, was generally at depths greater than 12 meters.

Diaptomus minutus was common at all stations at all locations in this survey except station 1. Although Watson (1974) stated that *D. minutus* was excluded from shallow waters, it was identified from samples taken at depths less than five meters in 1974.

Patalas (1972) suggested that the ratio of calanoid copepods to cyclopoid copepods plus cladocera was inversely related to increasing nutrients in the oligotrophic Great Lakes. In 1974, substantially lower ratios of calanoid/(cyclopoid plus cladocera) occurred in September than in June (35 percent vs. 67 percent) at every location except Lower Portage Entry and Isle Royale. The only location that did not have at least 50 percent calanoid copepods in the spring was Lower Portage Entry (28 percent), which may indicate nutrient enrichment at this location. Isle Royale had a higher percentage (66) of calanoids in the fall. If Isle Royale is considered apart from other Michigan nearshore waters, the 1974 data indicate Michigan's nearshore Lake Superior waters are enriched during late summer. This enrichment appears to be a natural characteristic of nearshore waters resulting from seasonal increases in water temperature and nutrient runoff from adjacent land and atmospheric inputs.

The numbers of rotifers in the nearshore Lake Superior waters during the summer of 1974 were highly variable. The location means for rotifers ranged from 401 and 451 rotifers$/m^3$ at Isle Royale in August and June, respectively, to 5201$/m^3$ at Carp River during June.

The most common rotifers at all locations were *Asplanchna*, *Keratella*, *Filinia* and *Polyarthra*. *Kellicottia*, *Brachionus* and *Conochilus* were usually present but in lower numbers. *Gastropus* was found at three of twelve locations but only in the fall. The occurrance of *Polyarthra*, *Asplancha*, *Filinia* and *Keratella*, which Nauwerck (1972) classified as mesotrophic and coldwater eutrophic genera, indicates some enrichment in the nearshore waters. However, the frequent occurrence of *Kellicottia* reflects the general oligrophic nature of these waters. Although there were no statistically significant differences between early-and late-summer rotifer numbers, some species changes were noted. Differences within stations did occur. Rotifers were more abundant (3 to 10 times) at stations nearest the shore at all locations except at Ontonagon during both seasons, and at Isle Royale in fall. The mean number of rotifers found at station 1 was 3250 ± 3049$/m^3$ while the mean of all other stations was 920 ± 652$/m^3$.

Benthic Macroinvertebrates

Only a limited amount of benthic macroinvertebrate literature is available for Lake Superior, most of which has been reviewed by Cook and Johnson (1974). Hiltunen (1969), Adams and Kregear (1969), and Schelske and Roth (1973) found benthic macroinvertebrate assemblages in the profundal zone of Lake Superior typical of deep cold oligotrophic lakes. Organisms found generally belonged to four major taxa: Oligochaeta, Chironomidae, Sphaeriidae, and the glacial marine relict amphipod, Pontoporeia affinis. *P. affinis* was reported by Henson, et al. (1973) to be the single most important benthic organism in Lake Superior. They believed any reduction in P. affinis numbers could disrupt the entire ecosystem of the lake.

The oligochaetes, chironomids and sphaeriids have only recently been taxonomically described at the generic or specific level by Brinkhurst (1964, 1965), Brinkhurst, et al. (1966, 1968, 1971), and Hiltunen (1969). The lumbriculid, Stylodrilus heringianus; the tubificids, Limnodrilus profundicola, Tubifex kersleri americanus, Peloscolex variegatus, P. superiorensis and Rhyacodrilus montanus; and many Naididae are restricted to oligotrophic lakes such as Lake Superior (Hiltunen, 1969, Cook and Johnson, 1974). S. heringianus is the dominant profundal oligochaete in Lake Superior and the naidid Stylaria lacustris is an important component of the deep-water benthos of Lake Superior (Adams and Kregear, 1969).

Typical oligotrophic chironomid assemblages include Heterotrissocladius, Protanypus, Paracladapelma, Monodiamesa, Potthastia cf. longimanus, Paralauterborniella, Stictochironomus and Micropsectra. Heterotrissocladius and Protanypus were reported to be the primary profundal chironomids in Lake Superior (Schelske and Roth, 1973 and Henson, 1966).

Because the Sphaeriidae are difficult to identify, the ecological significance of this group has not been adequately documented. Pisidium conventus and Sphaerium nitidum are coldwater species (Brinkhurst, et al. 1968) and have been reported in western Lake Superior (Hiltunen, 1969).

Studies of benthos in nearshore harbor and embayment areas of Lake Superior have been conducted primarily to assess the impact of municipalities, pulp mills and mining operations (German 1967, 1968; German and Pugh, 1969; Henson et al. 1973; Winter 1968; MWRC 1957, 1969; and Aquatic Research Group 1975). Since most studies are in impacted areas, the distribution and ecology of the benthos in unaffected nearshore waters are not adequately known. Cook and Johnson (1974) stated the nearshore fauna had a greater species diversity than the profundal zone due to a wider range of microhabitats in the nearshore waters. Although Pontoporeia affinis is the dominant profundal species, in the nearshore waters, the fauna is dominated by oligochaetes and chironomids (Hiltunen 1969).

During 1974, twelve locations along Michigan's Lake Superior shoreline were sampled for benthic macroinvertebrates. These locations were specifically chosen because of their particular characteristics. Areas of high water quality were chosen to serve as background references for areas which were impacted. From 1 to 13 stations per location were sampled, the number depending on prior knowledge of direct or indirect discharges to Lake Superior from industry or municipalities. In 1975, Carp River (Marquette Harbor) was sampled at four stations and Munising Harbor was resampled at four stations.

Five Taxonomic groups Pontoporeia affinis, sphaeriids, oligochaetes, chironomids and "other" taxa were used to identify major changes in benthic macroinvertebrates in the areas. The assumption was made that the presence of high numbers of P. affinis and sphaeriids, coupled with low numbers of total organisms (number/m^2) would indicate background or non-impacted areas (Table 6). Con

Table 6. Mean numbers of benthic macroinvertebrate major taxonomic groups at selected locations in nearshore Lake Superior, 1974 and 1975
Entries expressed as organisms/m² unless otherwise noted

	Number of Stations	Number of Taxa	Total Number/Station			P. affinis	Oligochaetes	Chironomids	Sphaeriids	"Other" taxa
			Mean	Standard Deviation	Range					
Background										
Black River	1	11	815	---	--- - ---	196	303	234	76	6
Eagle Harbor	1	8	963	---	--- - ---	716	13	215	0	19
Isle Royale	3	12	306	100	214- 412	181	52	44	15	13
Big Bay	2	27	760	773	213- 1306	165	326	213	38	19
Grand Marais	3	25	359	216	157- 587	30	177	148	0	4
Whitefish Point	3	46	3757	1827	1727- 5269	853	2028	304	401	171
Impacted (enrichment)										
Ontonagon	12	67	2682	2511	88- 8008	67	2126	472	10	7
Lower Portage Entry	4	42	1717	490	1158- 2278	426	392	575	161	163
Presque Isle	7	84	2847	2751	525- 8832	261	1535	853	109	89
*Marquette Harbor	4	54	2639	2960	183- 6706	202	1425	771	54	188
Carp River	7	48	1356	1405	562- 4475	25	695	628	0	7
Munising	13	98	10541	14719	1462-56652	900	7275	974	357	1036
*Munising	4	43	8035	12625	1293-26967	795	6232	545	348	116
Impacted (mine wastes)										
Upper Portage Entry	4	18	134	87	113- 247	29	3	100	0	5

*1975 Data

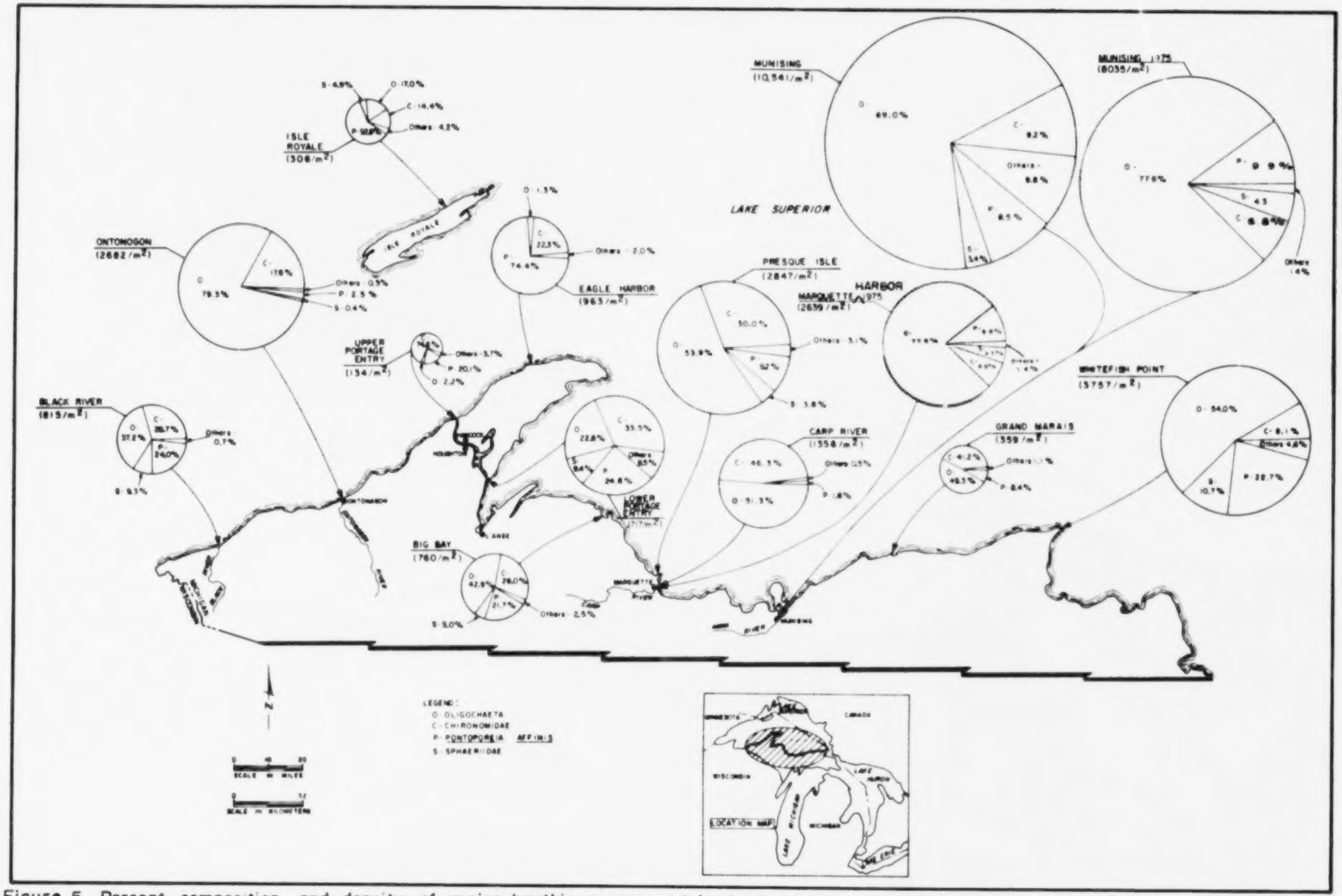

ISLE ROYALE (308/m2)
S-4.9%
O-17.0%
C-14.4%
Others-4.2%
P-59.5%
ONTONOGON (2682/m2)
O-79.3%
C-17.6%
Others-0.3%
P-2.5%
S-0.4%
EAGLE HARBOR (963/m2)
O-1.3%
C-22.3%
Others-2.0%
P-74.4%
UPPER PORTAGE ENTRY (134/m2)
Others-3.7%
P-20.1%
O-2.2%
BLACK RIVER (815/m2)
O-37.2%
C-28.7%
Others-0.7%
P-24.0%
S-9.3%
LOWER PORTAGE ENTRY (717/m2)
O-22.8%
C-35.5%
Others-8.5%
S-8.4%
P-24.8%
BIG BAY (760/m2)
O-42.8%
C-28.0%
P-21.7%
Others-2.5%
S-5.0%
LAKE SUPERIOR
MUNISING (10,541/m2)
O-69.0%
C-9.2%
Others-9.8%
P-8.5%
S-3.4%
MUNISING 1975 (8035/m2)
O-77.6%
P-9.9%
S-4.3
C-6.8%
Others 1.4%
PRESQUE ISLE (2847/m2)
O-53.9%
C-30.0%
Others-3.1%
P-9.2%
S-3.8%
MARQUETTE HARBOR 1975 (2839/m2)
O-77.6%
P-9.8%
Others-1.4%
CARP RIVER (1358/m2)
C-46.3%
O-51.3%
Others-0.5%
P-1.8%
GRAND MARAIS (359/m2)
C-41.2%
O-49.3%
Others-1.1%
P-8.4%
WHITEFISH POINT (3757/m2)
O-54.0%
C-8.1%
Others-4.6%
P-22.7%
S-10.7%
ONTONAGON
HOUGHTON
L'ANSE
MARQUETTE
MUNISING
RIVER
N
0 40 80
SCALE IN MILES
0 32
SCALE IN KILOMETERS
LEGEND:
O-OLIGOCHAETA
C-CHIRONOMIDAE
P-PONTOPOREIA AFFINIS
S-SPHAERIIDAE
LOCATION MAP
MINNESOTA
CANADA
WISCONSIN
MICHIGAN
LAKE MICHIGAN
LAKE HURON
LAKE ERIE

Figure 5 Percent composition and density of major benthic macroinvertebrate taxonomic groups in nearshore Lake Superior, 1974 and 1975.

versely, impacted areas would have lower densities of *P. affinis* and sphaeriids as well as large numbers of total organisms/m^2. Tables A-13 and A-14 summarize the benthic macroinvertebrate data collected from the nearshore waters of Lake Superior during 1974 and 1975.

With one exception (Whitefish Point), the background locations were dominated by oligotrophic indicator organisms, principally *Pontoporeia affinis*; the oligochaetes *Stylodrilus heringianus*, enchytraeids and *Aulodrilus limnobius*; the naidids, *Stylaria lacustris* and *Piquetiella michiganensis*; and the chironomids *Heterotrissodalius*, *Micropsectra*, *Paracladapelma* and *Monodiamesa*. Other taxa included the pelecypod, *Pisidium*; representatives of the trichopteran family, Hydroptiliidae; the ephemeropteran, *Baetis*; and the coleopteran, *Macronychus glabratus*. Only *P. affinis* and *Pisidium* were common at all background stations (Figure 5).

The background locations had low numbers of taxa and organisms, generally averaging less than 1000 organisms/m^2, except at Whitefish Point which averaged 3757 organisms/m^2. The benthic macroinvertebrates at Whitefish Point were dominated by oligotrophic indicator forms such as *Pontoporeia affinis*, *Stylodrilus heringianus*, *Monodiamesa*, and *Heterotrissocladius*. Increased numbers of organisms (3757 mean total organisms/m^2) and taxa (46), including pollution-tolerant forms such as *Peloscolex ferox* and *Limnodrilus hoffmeisteri* may indicate nutrient enrichment or an unusually rich habitat at this location.

The benthic macroinvertebrate communities at the impacted locations had significantly higher numbers of taxa, more than 1,000 organisms/m^2, and were dominated by oligochaetes and chironomids with a corresponding decrease in *Pontoporeia affinis* and sphaeriids. One exception was Upper Portage Entry. The benthic community at this location was dominated by chironomids (*Chironomus* and *Polypedilum*); had low numbers averaging 134 organisms/m^2, and had few taxa (18). This impact is probably due to past coppermine wastes (Aquatic Research Group 1975).

Lower Portage Entry and Carp River appear to be areas of moderate nutrient enrichment as shown by changes in the numbers and taxa of oligochaetes and chironomids, as well as the greater abundance of *Pontoporeia affinis* and other taxa. Compared to the background locations, these two locations have more taxa, greater numbers/m^2 and more pollution-tolerant forms. Enrichment at Lower Portage Entry has not excluded intolerant forms, indicating less enrichment to this oligotrophic system than at the Carp River location.

Marquette Harbor, Munising, Ontonagon and Presque Isle were dominated by oligochaetes and midges, both in numbers of taxa and organisms/m^2. The Marquette Harbor samples indicated a degraded benthic macroinvertebrate community near the shore that improved further offshore. The mean total number of organisms was 2639 organisms/m^2, dominated by oligochaetes (78 percent). The breakwall at this site restricts open lake water from mixing, and increases the accumulation of organic materials and nutrients contributed by the Dead River. The resulting enriched conditions are reflected in the large percentage of oligochaetes (48%) and elevated numbers of organisms ($\bar{x}$ = 6706/m^2) at station 1 at the Dead River mouth. Lakeward of the breakwall, the community was less degraded as shown by lower densities of pollution-tolerant forms (*Cryptochironomus*, *Cricotopus* and *Polypedilum* cf. *laetum*) at station 3 and the dominance of *Pontoporeia affinis* (47 percent), one of the primary oligotrophic indicator species, at station 4.

In 1974, Munising had the highest density (10,540 organisms/m^2) of all Lake Superior locations. The benthic community offshore from the Anna River was dominated by pollution-tolerant forms, reflecting inputs of nutrients from municipal sewage and paper mill waste discharges and restricted water circulation. The benthic community throughout the bay was dominated by oligochaetes (*Peloscolex ferox*, *Aulodrilus pluriseta* and immature oligochaetes), the isopod *Asellus* and the chironomids *Procladius*, *Ablabesmyia*, *Microtendipes*, and *Tanytarsus*. Intolerant species such as *Stylodrilus heringianus*, *Pontoporeia affinis* and *Heterotrissocladius* were present but not dominant. Benthic macroinvertebrates were sampled in 1975 at four stations, two of which were in the degraded zone indicated by the 1974 data, and two further lakeward but within the bay. Similar organisms were present in the duplicated 1974 stations. The river-mouth station was severely degraded with 88 percent oligochaetes (23,864/m^2) and no intolerant forms were found. Stations further offshore showed improved conditions, with oligochaetes ranging from 19 to 22 percent (247 to 410/m^2), and pollution-intolerant forms (*P. affinis* and sphaeriids) comprising 74 to 88 percent of the organisms. The total numbers of organisms were relatively low, ranging from 1293 to 2058 organisms/m^2.

In 1957, the benthic community in South Bay at Munising was biologically depressed (MWRC, 1957). In 1968, as in 1974 and 1975, offshore stations had diverse benthic communities, while stations in the vicinity of Kimberly Clark and the mouth of the Anna River (which receives the effluent from the municipal wastewater treatment plant) had a very limited benthic community dominated by pollution-tolerant midges (*Procladius*, *Prodiamesa*) and oligochaetes (*Limnodrilus*) (MWRC, 1968). Comparisons between the 1974-75 benthic data and data collected over the past 18 years indicated no apparent improvement of the benthic macroinvertebrate community in Munising Harbor.

Ontonagon and Presque Isle did not have as many taxa (67 and 84, respectively) or numbers of organisms/m^2 (2682 and 2847, respectively) as were found at Munising, but oligochaetes and chironomids dominated the benthic community at the former locations. The benthic macroinvertebrates at Ontonagon included naidids (*Uncinais uncinata*, *Piquetiella michiganenis*), tubificids (*Limnodrilus hoffmeisteri*, *Aulodrilus limnobius* and immature forms), low numbers of the limbriculid, *Stylodrilus heringianus*, and chironomids (*Potthastia*, *Stictochironomus*, *Chironomus*, *Monodiamesa tuberculata* and *Heterotrissocladius*). The amphipod, *Pontoporeia affinis*, although present at all but one station, was not abundant.

The benthic macroinvertebrate community at Presque Isle was dominated by oligochaetes and chrionomids, with *Pontoporeia affinis* and *Heterotrissocladius* abundant. Oligochaetes present at nearly all stations included *Stylodrilus heringianus*, *Arcteonais lomondi*, *Piquetiella michiganensis*, *Uncinais uncinata*, *Limnodrilus hoffmeisteri*, *Peloscolex ferox* and immature forms. The isopod *Asellus* was also present in low numbers. Chironomids present at nearly every station included *Procladius*, *Monodiamesa depectinata*, *M. tuberculata*, *Potthastia* cfr. *longimanus*, *Heterotrissocladius*, *Chironomus*, *Paracladapelma*, *Phaenopsectra*, *Polypedilum*, and *Tanytarsus*.

Contaminants in Fish

Excessive levels of metals and organic contaminants have been found in fish of the Great Lakes. Elevated mercury levels in fish from Lake St. Clair led to a ban on commercial fishing in that lake. High polychlorinated biphenyls (PCB), DDT and dieldrin concentrations in lake trout, coho salmon and chubs have resulted in a ban on commercial fishing of certain age classes of these species in Lake Michigan. High levels of DDT and PCB have been identified as the cause of reduced reproductive success of fish, fish-eating birds and animals; as a result, tolerance limits for various contaminants have been set by both the United States and Canadian governments to protect public health and wildlife.

The Canadian Food and Drug Directorate (CFDD, 1972) set the following maximum allowable levels for heavy metals in freshwater animal products: arsenic, 5 mg/kg; lead, 10 mg/kg; copper, 100 mg/kg; mercury, 0.5 mg/kg; and zinc, 100 mg/kg. The United States Food and Drug Administration (USFDA) has also set the tolerance-limit for human consumption of mercury in edible fish fillets at 0.5 mg/kg. A court ruling raised this concentration to 1.0 mg/kg mercury as of June 1978.

The GLWQA has an objective for total PCB level in whole fish of 0.1 mg/l for the protection of fish-eating birds and animals, and 1.0 mg/kg for DDT in whole fish (GLWQA 1978). The USFDA has set a tolerance-limit of 5.0 mg/kg for PCB and 5.0 mg/kg for total DDT in edible fish tissues. A tolerance limit of 2.0 mg/kg for PCB in edible fish tissue was set by the Canadian Food and Drug Directorate in 1972. The tolerance-limit recommended by the USFDA for dieldrin and the Great Lakes Water Quality Agreement for aldrin plus dieldrin in fish flesh is 0.3 mg/kg (GLWQA 1978).

Concentrations of heavy metals in Great Lakes fish have been discussed by Lucas *et al*. (1970), Uthe and Bligh (1971), Beal (1974), and Thommes, *et al*. (1972). Thommes *et al*. (1972) reported mercury concentrations in burbot and lake trout which exceeded the pre-June 1978 USFDA action level of 0.5 mg/kg.

In Lake Superior there are two distinct subspecies of lake trout which are recognizable from exterior morphological characteristics. Within the context of this report *Salvalinus namaycush namaycush* are described as lean lake trout and *Salvalinus namaycush siscowet* are described as fat lake trout.

In Lake Superior, concentrations of heavy metals were generally low. Copper, zinc, lead and cadmium concentrations were well below GLWQA criteria for all fish (Table 7). However, over 40% of the lake trout analyzed in 1974 exceeded the pre-January 1978 USFDA action level for mercury. Only 3.0% exceeded the new action level of 1.0 mg/kg. Actual location means were variable, ranging from 0.01 mg/kg in mottled sculpins to 0.71 mg/kg in lake trout.

Table 7. Mean concentrations of selected metals in Lake Superior fish, 1974 and 1975. Entries expressed as mg/kg wet weight basis for edible fillets, except for mottled sculpin which were composites of gutted fish. All species, except mottled sculpins were collected in 1974.

Location	Fish Species	N	Mercury mg/kg	Copper mg/kg	Zinc mg/kg	Lead mg/kg	Cadmium mg/kg
Whitefish Point	Lake trout	13	0.30	0.54	3.80	0.39	0.02
	Fat lake trout	10	0.50	0.35	2.87	0.45	0.02
Grand Marais	Lake trout	14	0.39	----	----	----	----
Munising	Herring	3	0.18	----	----	----	----
	Lake trout	22	0.44	----	----	----	----
	Fat lake trout	19	0.71	----	----	----	----
	Whitefish	2	0.04	----	----	----	----
Marquette	Lake trout	25	0.32	----	----	----	----
	Fat lake trout	12	0.64	----	----	----	----
	Whitefish	3	0.07	----	----	----	----
Big Bay	Lake trout	23	0.26	----	----	----	----
Lower Portage Entry	Herring	6	0.12	----	----	----	----
	Lake trout	15	0.21	0.36	3.11	0.26	0.03
Bete Grise	Whitefish	6	0.16	----	----	----	----
Copper Harbor	Lake trout	12	0.36	----	----	----	----
Upper Portage Entry	Lake trout	12	0.45	0.35	0.34	0.30	0.02
Black River	Lake trout	5	0.33	0.40	3.44	0.36	0.02
	Fat lake trout	17	0.58	0.29	3.12	0.28	0.04
Isle Royale	Fat lake trout	12	0.58	----	----	----	----
Little Girls Pt.	Lake trout	3	0.22	0.56	6.16	0.25	0.02
	Herring		0.61	1.1	22.45	0.39	0.22
	Whitefish		0.06	0.82	8.0	0.23	0.05
		1975					
Whitefish Point	Mottled sculpin	18	0.04	0.82	11.90	1.5	0.09
Grand Marais	Mottled sculpin	28	0.03	0.66	11.70	1.4	0.07
Munising	Mottled sculpin	18	0.07	----	----	----	----
Marquette	Mottled sculpin	10	0.02	----	----	----	----
Presque Isle	Mottled sculpin	13	0.04	----	----	----	----
Big Bay	Mottled sculpin	18	0.05	0.95	12.3	1.2	0.12
Huron Bay	Mottled sculpin	28	0.05	0.75	12.15	1.3	0.10
L'Anse	Mottled sculpin	27	0.02	0.66	11.78	1.4	0.08
Lower Portage Entry	Mottled sculpin	20	0.02	0.72	11.86	1.2	0.10
Grand Traverse Bay	Mottled sculpin	22	0.02	----	----	----	----
Copper Harbor	Mottled sculpin	30	0.03	0.90	11.92	1.3	0.11
Eagle Harbor	Mottled sculpin	13	0.02	----	----	----	----
Eagle River	Mottled sculpin	13	0.04	----	----	----	----
Upper Portage Entry	Mottled sculpin	27	0.05	1.22	12.45	1.5	0.13
Carver's Bay	Mottled sculpin	40	0.03	0.83	11.81	1.2	0.11
Big Iron River	Mottled sculpin	28	0.03	0.90	12.13	1.4	0.11

Table 7. (continued)

Location	Fish Species	N	Mercury mg/kg	Copper mg/kg	Zinc mg/kg	Lead mg/kg	Cadmium mg/kg
Black River	Mottled sculpin	9	0.03	----	----	----	----
Isle Royale	Mottled sculpin	-	0.06	1.3	34.8	0.15	0.05
GLWQA Tolerance Limit (whole fish)			0.5	100	100	10	----
Pre-Jan. 1978 USFDA Tolerance Limit (edible portions)			0.5				
New USFDA Tolerance Limit (edible portions)			1.0				

---- = No sample analysis for this parameter

Pesticides and other organic contaminants in fish have been discussed by Reinert (1970), Swain (1975) and the Great Lakes Environmental Contaminants Survey (GLECS) (1973), (1974) and (1975). Reinert (1970) reported DDT and dieldrin levels of various Lake Superior fish species and the GLECS reports showed the concentrations of dieldrin, DDT, PCB and mercury. Swain discussed persistent organics and heavy metals in nearshore western Lake Supieror (Swain, 1975).

In Lake Superior, concentrations of chlordane, methoxychlor, benzene, hexachloride (BHC), hexachlorobenzene (HCB), hexachlorobutadiene (HCBD, dibutyl-n-phthalate (DBP), diethyl hexylphthalate (DEHP) and polybrominated biphenyl (PBB) were below detection levels in all samples collected (Table 2). However, low concentrations of chlordane, BHC, HCB, HCBD and DBP were detected by Swain using more sensitive techniques (Swain 1975).

Average dieldrin concentrations were well below USFDA action levels for lake trout, and whitefish collected in 1974 and mottled sculpins collected in 1975.

In 1974, total DDT was present in all samples with location averages ranging from 0.17 mg/kg in herring at Munising to 5.10 mg/kg in fat lake trout at Black River Harbor.

The mean total DDT concentration for fat lake trout at Black River Harbor exceeded the USFDA 5.0 mg/kg action level (Table 8), as did some individial fat and lean lake trout from the Lower Portage Entry, Copper Harbor, Marquette and Munising. The highest value was 26.02 mg/kg in a fat lake trout collected near Munising. Although nearly 20% of the fat lake trout values exceeded the USFDA limit, total DDT was significantly lower in lean lake trout even though they exceeded the GLWQA at more than half of the locations sampled (Table 8). Average total DDT concentrations in lean lake trout ranged from 0.47 to 3.31 mg/kg similar to other authors (Swain 1975).

Whitefish and herring also had low levels of total DDT in 1974 and only herring at Lower Portage Entry exceeded the GLWQA objectives of 1.0 mg/kg total DDT.

Mottled sculpins collected in 1974 contained very low levels of total DDT ranging from below detection to 0.32 mg/kg. This maximum concentration is less than 10 percent of the current USFDA action level for DDT and the upper levels found in fat lake trout. DDT residues were not detectable in sculpins from L'Anse, Lower Portage Entry or Huron Bay. Carver's Bay, Eagle River and Whitefish Bay were the only locations where DDT levels in sculpin were over 0.20 mg/kg. Sculpins from these three locations, as well as those from Big Bay, also contained measurable dieldrin concentrations.

In 1974, mean PCB levels were highly variable between species, ranging from 8.37 mg/kg in fat lake trout at Black River to 0.22 mg/kg in herring from Munising. Concentrations within species were variable, as indicated by lean lake trout from Lower Portage Entry, where 7 of 15 lake trout had less than detectable PCB levels while others in the same location ranged as high as 6.81 mg/kg PCB. Grand Marais, Big Bay, Bete Grise and Little Girls Point were the only locations where no fish exceeded the tolerance

Table 8. Mean concentrations of selected organic contaminants in Lake Superior fish, 1974 and 1975. Entries expressed as mg/kg wet weight basis for edible fillets. Mottled sculpin were composites of gutted fish. All species except mottled sculpin were collected in 1974.

Location	Fish Species	N	Total DDT mg/kg	PCB mg/kg	Dieldrin mg/kg
		1974			
Whitefish Point	Lake trout	13	0.74	0.98	0.03
	Fat lake trout	10	1.82	3.18	0.05
Grand Marais	Lake trout	14	1.03	1.61	0.02
Munising	Herring	3	0.17	0.22	0.01
	Lake trout	22	3.31	3.11	0.04
	Fat lake trout	19	3.46	5.10*	0.04
	Whitefish		0.19	0.27	0.19
Marquette	Lake trout	25	1.35	1.95	0.02
	Fat lake trout	12	3.89	5.05*	0.08
	Whitefish	3	0.29	0.31	0.02
Big Bay	Lake trout	23	0.85	1.13	ND
Lower Portage Entry	Herring	6	1.18	1.03	----
	Lake trout	15	1.35	1.06	0.02
Bete Grise	Whitefish	6	0.69	0.89	0.08
Copper Harbor	Lake trout	12	2.44	2.99	0.02
Upper Portage Entry	Lake trout	12	0.98	1.17	0.02
Black River	Lake trout	5	1.51	2.09	0.03
	Fat lake trout	17	5.11*	8.37*	0.07
Isle Royale	Fat Lake trout	12	2.10	2.33	ND
Little Girls Pt.	Lake trout	3	0.47	1.25	0.03
		1975			
Whitefish Point	Mottled sculpin	18	0.23	0.44	0.02
Grand Marais	Mottled sculpin	28	0.10	0.29	----
Munising	Mottled sculpin	18	0.03	0.09	----
Marquette	Mottled sculpin	10	0.06	0.15	----
Presque Isle	Mottled sculpin	13	0.03	----	----
Big Bay	Mottled sculpin	18	0.09	0.15	0.01
Lower Portage Entry	Mottled sculpin	20	0.09	0.14	----
Grand Traverse Bay	Mottled sculpin	22	0.02	TR	----
Copper Harbor	Mottled sculpin	30	0.04	0.09	----
Eagle Harbor	Mottled sculpin	13	0.10	0.15	----
Eagle River	Mottled sculpin	13	0.43	0.46	0.03
Carvers Bay	Mottled sculpin	40	0.45	0.37	0.03
Big Iron River	Mottled sculpin	28	0.05	0.09	----
Black River	Mottled sculpin	9	0.02	----	----
GLWQA objective (whole fish)			1.0	0.1	0.3**
USFDA Tolerance Limit (edible portions)			5.0	5.0	0.3

ND = not detectable
---- = no sample analysis for this parameter

* = exceeds USFDA tolerance limit
TR = trace
** = aldrin plus dieldrin

limit. Mean location PCB levels exceeded the 5.0 mg/kg tolerance limit in fat lake trout at Munising, Marquette, and Black River (Table 8) (Figure 6). In 1974, the lakewide average for lake trout was 3.57 mg/kg PCB.

The highest mean PCB levels in lean lake trout occurred in Munising and Copper Harbor, but these locations were not significantly different from the other location. While fish containing high levels of PCB were found at these two locations, there were also many fish collected which had low levels. PCB concentrations in whitefish and herring from all locations were lower than lake trout, averaging 0.54 mg/kg.

In 1975, low PCB levels were found in mottled sculpin with mean values ranging from less than detection to 0.46 mg/kg. Sculpins at four locations, Carver's Bay, Eagle River, Grand Marais, and Whitefish Point had levels higher than 0.20 mg/kg (Table 8), while levels at all other locations were very low.

The levels of DDT and PCB were generally higher in the larger fish, as demonstrated by a linear regression analysis performed on lake trout data. Lake trout were used because they were captured at nearly all locations and in most size groups. Other authors (Swain 1975) have indicated that bioaccumulation may be more related to exposure experience and lipid content than to fish size.

An analysis of the trends of these fish contaminants based on the GLECS data were completed only for lake trout in Lake Superior in 1974, 1975 and 1976. Insufficient data for other fish collected during these years prevented analysis. Fat and lean trout were tested separately in 1975 and 1976 but not in 1974, when those subspecies were not separately coded and subsequently could not be differentiated by the computer.

Lean lake trout contained significantly lower concentrations of dieldrin than fat lake trout based on combined 1975 and 1976 data (Table 9). Dieldrin in lean lake trout was significantly higher in 1976 and 1975, while fat lake trout dieldrin levels were not significantly different in these two years. None of the average concentrations exceeded the U.S. FDA action level, but 7.7 percent of the individual lean lake trout sampled in 1976 exceeded this value. The trend showed an increase in dieldrin in Lake Superior lake trout based on data from 1974 through 1976.

Concentrations of DDT in fat lake trout were significantly greater than in lean lake trout based on combined 1975 and 1976 data (Table 10). Lean lake trout DDT concentrations were significantly greater in 1976 than in 1975 and in 1976, 11.5% of lean lake trout exceeded the U.S. FDA action level.

There were no significant differences in the DDT concentrations in fat lake trout between 1975 and 1976. However, 44.2 and 19.0 percent of the individual fish exceeded the U.S. FDA action level in 1975 and 1976, respectively. The average concentration of DDT in fat lake trout in 1975 was 3.35 mg/kg above the action level while the 1976 mean value was below this value (Table 10). The data showed an increase in DDT concentrations in Lake Superior lake trout based on data from 1974 to 1976.

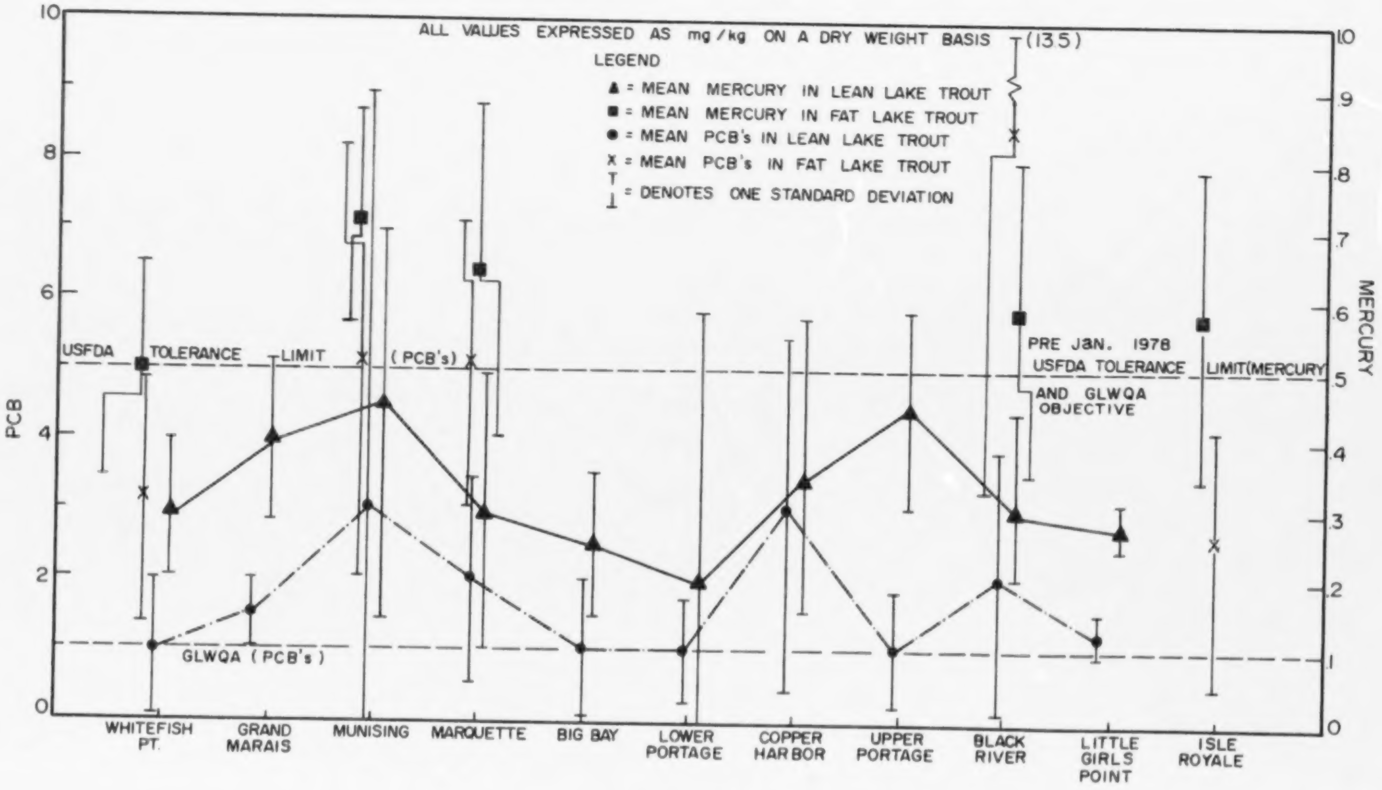


Figure 6 Mean PCB and mercury concentrations in lake trout from Lake Superior, 1974

Table 9 Trends of dieldrin in Lake Superior lake trout 1974-1976.

Year and significance α = 0.05	Number and percent of samples exceeding U.S. FDA action level of 0.3 mg/kg #/total	%	Raw data (mg/kg wet weight) Mean	Standard deviation	Minimum value	Maximum value
All 1976>1975>1974[1]						
1974	1/253	0.4	0.048	0.049	0.005	0.310
1975	-	-	0.053	0.041	0.010	0.250
1976	2/47	4.3	0.086	0.075	0.010	0.400
Lean 1976>1975						
1975	0/122	-	0.038	0.022	0.010	0.120
1976	2/26	7.7	0.078	0.096	0.010	0.400
Fat 1975, 1976						
1975	0/52	-	0.089	0.053	0.010	0.250
1976	0/41	-	0.095	0.033	0.040	0.180
Fat> Lean (1975 and 1976)						
Lean	2/148	1.4	0.046	0.047	0.010	0.400
Fat	0/73	-	0.091	0.048	0.010	0.250

[1] Greater than indicators (>) are significantly different. Underline values are not significantly different from each other.

Table 10 Trends of DDT in Lake Superior lake trout, 1974-1976

Year and significance α = 0.05	Number and percent of samples exceeding U.S. FDA action level of 5.0 mg/kg #/total	%	Raw data (mg/kg wet weight) Mean	Standard deviation	Minimum value	Maximum value
All 1976>1974>1975[1]						
1974	45/253	17.8	2.69	3.18	0.05	26.02
1975	23/174	13.2	3.16	6.11	0.07	41.79
1976	7/47	14.9	3.52	4.94	0.23	33.12
Lean 1976>1975						
1975	0/122	-	0.95	0.74	0.07	4.17
1976	3/26	11.5	3.32	6.44	0.23	33.12
Fat 1975, 1976						
1975	23/52	44.2	8.35	9.28	1.06	41.79
1976	4/21	19.1	3.78	2.04	1.33	9.33
Fat > Lean (1975 and 1976)						
Lean	3/148	2.0	1.37	2.89	0.07	33.12
Fat	27/73	37.0	7.04	8.15	1.06	41.79

[1] Greater than indicators (>) are significantly different. Underline values are not significantly different from each other.

Concentrations of PCB in fat lake trout were significantly higher than lean lake trout for the combined 1975 and 1976 data (Table 11). Lean lake trout PCB levels were significantly higher in 1976 than the 1975 values. Only 2.5 and 15.4 percent of the individual fish analyzed exceeded the U.S. FDA action level in 1975 and 1976, respectively. There were no significant differences in fat lake trout during 1975 and 1976, but mean values exceeded the U.S. FDA action level in 1975 and approached this value in 1976. In addition, 67.3 and 47.6 percent of the fat lake trout exceeded this level during the respective years. Maximum values ranged up to 61.56 mg/kg in 1975. The data indicated no increase or decrease in the PCB concentrations in Lake Superior lake trout from 1974 through 1976.

Fat lake trout had significantly higher mercury concentrations than lean lake trout based on the combined 1975 and 1976 data (Table 12). Concentrations of mercury in lean lake trout were significantly higher in 1976 than in 1975. Fat lake trout were not significantly different, but 9.6% of the fat lake trout collected in 1975 exceeded the U.S. FDA action level. The data showed that mercury concentrations in Lake Superior lake trout were significantly higher in 1976 than 1974. Concentrations of mercury in 1975 were significantly lower than both other years. None of the yearly means exceeded the 1.0 mg/kg U.S. FDA action level for mercury, but 3.0 and 2.8 percent of the individual fish collected in 1974 and 1975, respectively, exceeded this value.

Table 11 Trends in PCB in Lake Superior lake trout, 1974-1976

Year and significance α = 0.05	Number and percent of samples exceeding U.S. FDA action level of 5.0 mg/kg #/total	%	Raw data (mg/kg wet weight) Mean	Standard deviation	Minimum value	Maximum value
All 1976, 1975, 1974[1]						
1974	63/253	24.9	3.57	3.81	0.005	24.00
1975	37/174	21.3	5.45	9.24	0.09	61.56
1976	14/47	29.8	3.89	4.45	0.34	27.75
Lean 1976>1975						
1975	3/122	2.5	1.69	1.38	0.09	8.60
1976	4/26	15.4	3.05	5.29	0.34	27.75
Fat 1976, 1975						
1975	35/52	67.3	14.25	13.13	1.73	61.56
1976	10/21	47.6	4.95	2.96	1.52	12.15
Fat > Lean (1975 and 1976)						
Lean	7/148	4.7	1.93	2.56	0.09	27.75
Fat	45/73	61.6	11.58	11.94	1.52	61.56

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[1] Greater than indicators (>) are significantly different. Underline values are not significantly different from each other.

Table 12 Trends in mercury in Lake Superior lake trout 1974-1976

Year and significance @ α = 0.05	Number and percent of samples exceeding U.S. FDA action level of 1.0 mg/kg		Raw data (mg/kg wet weight)			
	#/total	%	Mean	Standard deviation	Minimum value	Maximum value
All 1976>1974>1975 [1]						
1974	9/253	3.0	0.47	0.25	0.07	1.22
1975	5/174	2.8	0.39	0.26	0.03	1.20
1976	0/47	-	0.51	0.27	0.14	0.99
Lean 1976>1975						
1975	0/122	-	0.22	0.11	0.03	0.54
1976	0/26	-	0.37	0.24	0.14	0.91
Fat 1975, 1976						
1975	5/52	9.6	0.68	0.23	0.25	1.20
1976	0/21	-	0.66	0.23	0.34	0.99
Fat > Lean (1975 and 1976)						
Lean	0/148	-	0.25	0.15	0.03	0.91
Fat	5/73	6.8	0.67	0.22	0.25	1.20

[1] Greater than indicators (>) are significantly different. Underlined values are not significantly different from each other.

Summary

In general, Michigan's nearshore waters of Lake Superior were of high quality. Temperature, dissolved oxygen and nutrient profiles varied little with depth, indicating thorough mixing.

In relation to the other Great Lakes, low levels of dissolved solids, chlorophyll a and phosphorus were present, while nitrate and silica concentrations were high. Heavy metal concentrations were well within the criteria for aquatic life and drinking water, although in exceptions various parameters were noted at Big Bay, Grand Marais, Lower Portage Entry and Eagle Harbor. Organic chemicals were generally not detectable in Lake Superior nearshore waters except for diethylhexel-phthalate at one Carp River station. Low concentrations of DDT and DDE were detected everywhere, but PCBs were not detectable in any water samples, apparently because detection limits were not low enough. Scans for gross beta and gamma emissions in water indicated very low activity or levels below the minimum detectable activity.

Nearshore sediments were generally uncontaminated except at Munising. Sediment contamination at Ontonagon, Upper Portage Etnry, Eagle Harbor, Presque Isle, and Isle Royale was due to past mining activities and/or natural deposits of metals. Organic contamination at Ontonagon, Carp River, and Munising was primarily due to past wood and paper mill industries and municipal waste treatment plant discharges.

Biological populations also reflected high water quality. The nearshore Lake Superior waters were relatively free from fecal contamination except the river mouths at Carp River and Munising. Standing crops of phytoplankton were low, as indicated by algal densities and chlorophyll a concentrations at most locations. Enrichment indicated by mesotrophic species was limited to river mouths especially Carp River (Marquette). There were fewer abundant phytoplankton species in the fall with a reduction in diatoms and an increase in *Dinobryon*. *Rhodomonas minuta* and *Cyclotella* spp. were the most prevalent species during both seasons.

Zooplankton populations were dominated by diaptomid calanoids in the spring but calanoids were less abundant in the fall, due probably to seasonal increases in temperature. Crustacean zooplankton species associations, similar to those reported by other researchers, indicate oligotrophic water quality except at Lower Portage Entry. The species composition and density of the rotifer population indicate some enrichment of the very nearshore waters; reductions further offshore may be due to depth or seasonal changes.

The benthic macroinvertebrate community was impacted at Ontonagon, Presque Isle, Marquette Harbor and Munising, where the benthic communities were dominated by pollution-tolerant forms as a result of nutrient enrichment. Lower Portage Entry and Carp River communities reflected moderate enrichment while Upper Portage Entry communities were impacted by high copper concentrations.

Organic trace contaminants in fish were present at generally low levels except for DDT and PCB, which were above USFDA guidelines at several stations.

Elevated levels of these contaminants were evident in fat lake trout, with higher concentrations found in larger fish at Munising, Black River, Marquette, Isle Royale and Copper Harbor. Concentrations of PCB in most lake trout exceeded the GLWQA objectives. Mercury in fat lake trout also exceeded the pre-January, 1978 USFDA guidelines and the GLWQA objectives at all locations where they were collected. Approximately 10 percent of the fat lake trout also exceeded the new USFDA action level of 10 mg/kg.

The GLECS reports were available for limited trend analysis. The most recent GLECS data for lake trout, which was the only species in Lake Superior with sufficient information, covered a period from 1974 to 1976. Two subspecies were found (fat and lean) and fat lake trout had significantly higher concentrations of all contaminants than did lean lake trout.

In Lake Superior the concentrations of dieldrin, DDT and mercury in the lean and fat lake trout combined were significantly higher in 1976 than 1974, the years for which data is available. Concentrations of PCB however, did not change significantly during this same period.

SECTION VI

LAKE HURON

Introduction

Lake Huron is the third largest of the Great Lakes in volume (3535 km^3) and second largest in surface area (59,570 km^2). It ranks second in watershed population density and first in total shoreline length (5088 km) (Chandler, 1964). The chemical composition of Lake Huron waters is largely determined by two factors. First, Lake Huron is a large mixing basin for the outflows from Lakes Superior and Michigan. Schelske and Roth (1973) report conservative element concentrations from northern Lake Huron which approximate a mixture of 40 percent Lake Michigan and 60 percent Lake Superior waters. Second, large amounts of dissolved solids enter lower Lake Huron through Saginaw Bay via the Saginaw River, significantly increasing concentrations of dissolved materials in the lower lake.

The general flow of water in Lake Huron is from the Straits of Mackinac and the St. Marys River southeast along the Michigan coast to the outlet at Port Huron (Figure 7), although winds create short-term flow modifications (Ayers, 1962). Saginaw Bay currents generally move past Port Austin and south to Port Huron, but occasionally switch to the north toward Thunder Bay (Schelske and Roth, 1973). Many relatively shallow bays and harbors in Lake Huron are isolated from the main lake, resulting in distinct physical and chemical characteristics due to inputs from river mouths, other localized watershed influences, and the lack of water circulation.

The physical and chemical characteristics of Lake Huron generally indicate oligotrophic waters. Lake Huron generally has low specific conductance, low total dissolved solids, high transparancy, high dissolved oxygen, and uniform reactive phosphate throughout the water column. A trend toward mesotrophy has been reported by Schelske and Roth (1973) and Dobson, *et al*. (1974). Schelske and Roth (1973) found somewhat reduced silica and nitrate concentrations in surface waters relative to bottom waters. They also found that chlorophyll *a* levels in Saginaw Bay averaged nine times greater than concentrations at other Lake Huron locations. Dobson *et al*. (1974) found that productivity was increasingly seasonally variable, indicating mesotrophic conditions. They considered Saginaw Bay to be eutrophic and limnologically distinct from Lake Huron.

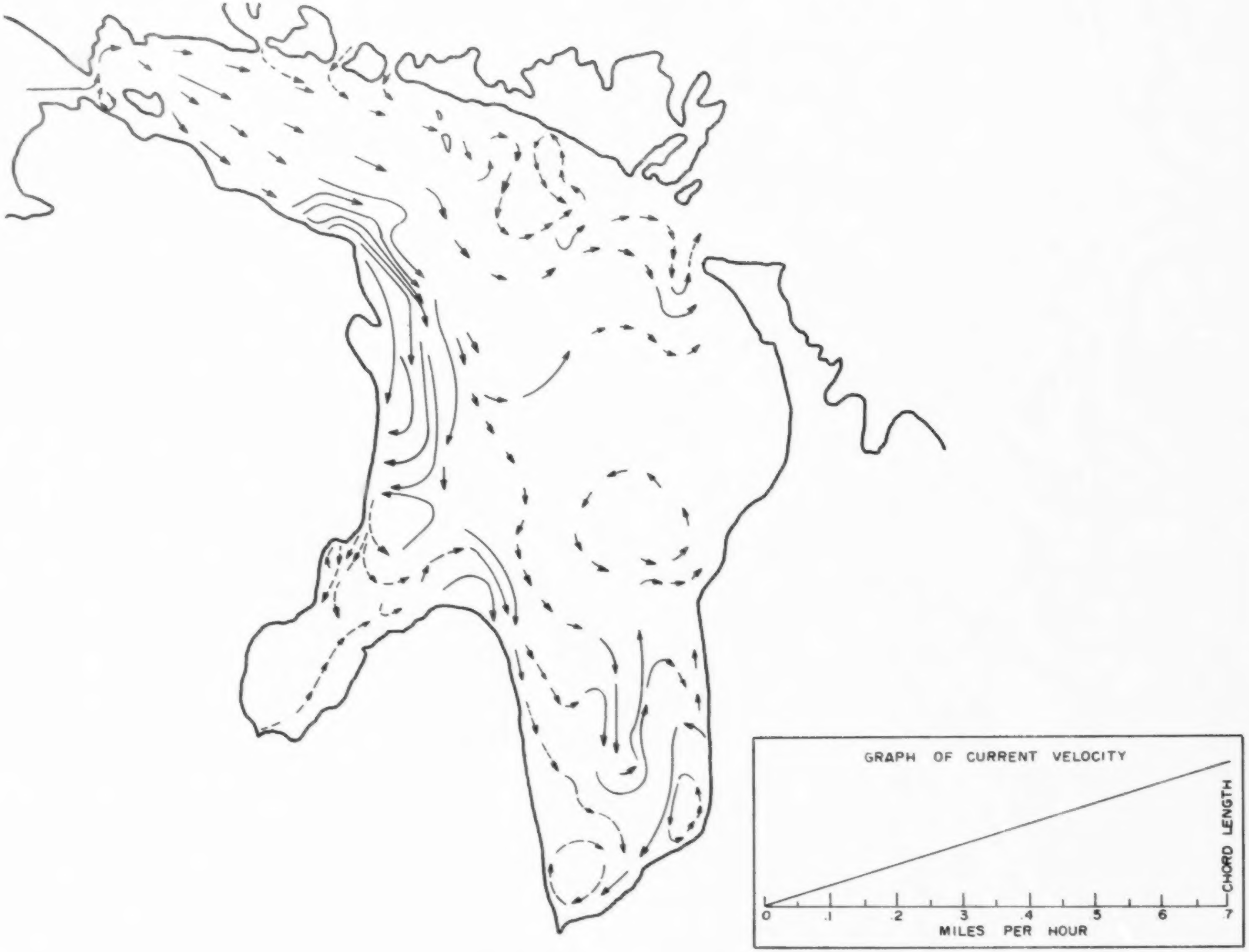
GRAPH OF CURRENT VELOCITY
CHORD LENGTH
0
.1
.2
3
.4
5
6
7
MILES PER HOUR

Figure 7 Typical Lake Huron surface currents (after IJC, 1977)

Physical and General Water Chemistry

Mean temperatures during 1974 ranged from 12.0° to 18.8°C in the spring with maximum temperatures recorded at Saginaw Bay. Fall mean temperatures ranged from 9.8° to 19.8°C. In 1975 mean location temperatures ranged from 8.8° to 21.2°C, with the highest temperatures (9°C greater than any other location) again found at Saginaw Bay. No stable thermal stratification was observed during either year.

Annual mean DO concentrations in 1974 ranged from 9.1 to 11.6 mg/l, with an overall lake mean of 10.4 ± 0.8 mg/l. Differences in oxygen concentrations between sampling periods and between locations were not significant. Dissolved oxygen was negatively correlated with some conservative ions, selected nutrients, temperature and chlorophyll a. Mean DO concentrations were similar in 1975, ranging from 10.7 to 13.3 mg/l, with a lakewide average of 11.0 ± 0.9 mg/l. Dissolved oxygen concentrations were near saturation levels at all locations during both years, with orthograde depth profiles which reflect oligotrophic waters.

In 1974, mean pH levels ranged from 7.8 to 8.2; however, in 1975, equipment failures prevented accurate pH measurement. There were no consistent variations with season, and differences between locations were not significant. Depth profiles reflected more alkaline waters at the surface due to uptake and incorporations of CO_2 by phytoplankton.

Mean total dissolved solids (TDS) concentrations ranged from 92 to 136 mg/l in 1974. No significant differences were found between sampling periods, but there were significant differences between locations. Background locations were not significantly different from each other. The impacted areas (Cheboygan, Alpena, Saginaw Bay and Harbor Beach) were not significantly different, but TDS concentrations at Alpena were substantially higher than at the background areas. The primary sources of TDS in Alpena were the Thunder Bay River and the Abitibi Corporation. The Lake Huron mean TDS concentrations (111 mg/l) for the background locations were approximately twice those for the Lake Superior mean (54 mg/l). Lake Huron background values indicate a general southerly increase in TDS throughout the nearshore Lake Huron waters. Thus, a general north to south increase in TDS and a corresponding decline in Lake Huron water quality appeared to occur and may be related to the southward increase in population and industrial activity.

During 1975, a similar TDS relationship existed, but the north to south trends were not as evident. The lakewide average was 127 ± 19 mg/l, with individual location means ranging from 88 to 144 mg/l. Total dissolved solids were strongly correlated with alkalinity, hardness, conductivity, calcium and magnesium; however, TDS were less correlated with phosphorus, ammonia, sodium, potassium, sulfate, silica, chlorophyll *a* and COD, and negatively correlated with nitrate.

In 1974, mean conductivity values ranged from 154 to 225 µmho/cm with a higher value in the spring than the fall. Significant differences were found between locations. Significantly lower values at Detour reflected the input of Lake Superior water from the St. Marys River, while those industrialized areas located at river mouths (Alpena, Cheboygan and Saginaw Bay) had significantly higher values. The increased conductivity values in the southern portion of the lake correspond to the observed change in TDS, both indicating that inputs from the industrialized watershed of Cheboygan, Alpena, and Saginaw Bay have a cumulative effect on Lake Huron water quality. Conductivity correlations were similar to those for TDS except for non-significant correlations with chlorophyll *a* and nitrate.

Chlorides and sulfates also reflected the north to south trends reported for total dissolved solids and conductivity. The location means for 1974 ranged from 3.8 to 9.9 mg/l and 10.8 to 20.4 mg/l for chlorides and sulfates, respectively, with sulfate concentrations highest at Alpena, and chloride highest at Saginaw Bay. Chlorides were moderately correlated with copper, magnesium, TDS and chlorophyll *a* and negatively correlated with dissolved silica. Sulfates were also moderately correlated with copper, magnesium, TDS, and chlorophyll a, in addition to phosphorus, nitrogen and COD, and negatively correlated with nitrates. In 1975, location means from chlorides and sulfates ranged from 4.0 to 16.0 mg/l and 11.0 to 22.0 mg/l, respectively, while lakewide means were 7.0 ± 4.0 mg/l chlorides and 15.0 ± 3.0 mg/l sulfate. The Saginaw Bay location mean was significantly higher than other location means for both ions in 1975.

Nutrients and Chlorophyll *a*

In 1974, nitrate concentrations in Lake Huron were lower and more variable than the Lake Superior levels. Mean NO_3-N concentrations at individual locations ranged from 0.140 to 0.264 mg/l. Nitrate levels were significantly lower in the surface waters than near the bottom, but there were no differences between spring and fall data. Nitrate was negatively correlated with the major ions, dissolved silica, alkalinity and hardness, and was positively correlated with total nitrogen. In 1975, NO_3-N means ranged from 0.142 to 0.280 mg/l, with a lakewide mean of 0.226 ± 0.040 mg/l. Cheboygan, Alpena and Saginaw Bay had significantly lower concentrations than the other locations during both years. The mean concentration for these three locations was 0.154 + 0.012 mg/l in 1974, and 0.165 ± 0.021 mg/l in 1975, while the 1974 and 1975 mean for the five background locations was 0.232 ± 0.019, and 0.256 ± 0.018 mg/l, respectively. The mean NO_3-N concentration for the latter five locations was similar to the lakewide average for Lake Superior (0.269 ± 0.022 mg/l). Apparently, increased primary production in the vicinity of Cheboygan, Alpena, and Saginaw Bay is sufficient to reduce nitrate concentrations, but not to low enough concentrations to limit algal growth.

In 1974, mean ammonia concentrations ranged from 0.002 to 0.029 mg/l with a lakewide mean of 0.011 ± 0.007 mg/l, approximately 1.5 times greater than the corresponding Lake Superior value. Only 8 percent of the ammonia values were below the detection limit (0.001 mg/l). Differences between locations and sampling periods were not significant, although Alpena, Saginaw Bay and Harbor Beach did have numerically higher concentrations. Ammonia was correlated with nutrients, chlorides and turbidity, and negatively correlated with dissolved oxygen.

In 1975, the average lakewide ammonia concentration was 0.005 ± 0.005 mg/l, with individual location means ranging from below detection to 0.016 mg/l at Alpena, which had the only elevated concentration in 1975.

Total nitrogen annual means ranged from 0.32 to 0.47 mg/l in 1974, with a lakewide average of 0.43 ± 0.06 mg/l. There were no locations or sampling period differences in 1974. In 1975, location means ranged from 0.32 to 0.71 mg/l, with a lakewide mean of 0.44 ± 0.12 mg/l. These concentrations were similar to Lake Superior's lakewide mean (0.40 ± 0.003 mg/l). Values for the Saginaw Bay location were significantly higher than other locations in 1975. At Saginaw Bay, most of the nitrogen occurred at organic nitrogen.

In 1974, reactive orthophosphate levels in Lake Huron were slightly higher and more variable than Lake Superior levels. Mean concentrations at individual locations ranged from 0.003 to 0.007 mg/l P with highest concentrations at Alpena. Approximately 35 percent of the values were below the detection level (0.002 mg/l). In 1975, mean concentrations ranged from less than 0.001 to 0.004 mg/l with a lakewide mean of 0.002 ± 0.001 mg/l, which reflects good water quality. Saginaw Bay had the highest reactive orthophosphate concentration, with Alpena second highest at 0.003 mg/l.

Mean total phosphorus concentrations in 1974 ranged from 0.004 to 0.022 mg/l, with significant difference between locations. Alpena had the highest concentration, followed by Saginaw Bay and Harbor Beach. Harbor Beach is periodically affected by water masses from Saginaw Bay.

The National Eutrophication Survey (EPA, 1974) reported that total phosphorus concentrations less than 0.010 mg/l were indicative of oligotrophic waters. Concentrations between 0.01 and 0.02 mg/l were mesotrophic and waters with total phosphorus over 0.020 mg/l were eutrophic. Therefore, according to these classifications Alpena (0.028 mg/l) was eutrophic, and Saginaw Bay (0.018 mg/l) and Harbor Beach (0.012 mg/l) were in the mesotrophic range. Total phosphorus was moderately correlated with chlorophyll a, calcium, sulfate, TDS, organic N, ammonia, turbidity, conductivity and COD and less correlated with reactive silica, alkalinity and hardness. During 1975, location means ranged from 0.003 to 0.032 mg/l, with a lakewide mean of 0.009 ± 0.010 mg/l. In 1975, Saginaw Bay (0.032 mg/l) would be considered eutrophic and Alpena (0.018 mg/l) would be considered mesotrophic.

Reactive silica levels in Lake Huron in 1974 were lower and more variable than silica levels in Lake Superior. The mean location concentrations ranged from 0.7 to 1.7 mg/l. The Lake Huron lakewide mean (1.0 ± 0.4 mg/l) was approximately one-half the Lake Superior mean concentration. Fall levels were lower than spring levels, even though there were no significant differences between sampling periods, locations or depths. Reactive silica was moderately correlated with calcium, magnesium, TDS and alkalinity, less strongly correlated with reactive and total phosphorus, organic nitrogen, conductivity and hardness, and negatively correlated with nitrate and chlorides (Table A-5). In 1975, mean reactive silica concentrations ranged from 0.6 mg/l in the southern portion of the lake to 2.0 mg/l at the northern locations, with a lakewide average of 1.2 ± 0.5 mg/l. Thus, a north to south decrease in silica was evident in 1975.

In 1974, mean chlorophyll a ranged from 1.7 to 10.6 µg/l with a lakewide mean of 4.8 ± 4.7 µg/l. Significant differences occurred between locations, but not between sampling periods. Alpena had the highest mean chlorophyll a concentration (10.6 µg/l) which was significantly higher than the mean concentrations for three locations north of Detour, Cheboygan and Presque Isle.

A significant north to south increase in chlorophyll a was observed during 1974. A linear regression of the control location mean chlorophyll a values on the approximate distance from Detour on the north to south axis was significant. Chlorophyll a was strongly correlated with COD, potassium, sulfate, TDS and hardness; moderately correlated with other major ions, total phosphorus, organic nitrogen, turbidity, alkalinity and temperature; and negatively correlated with dissolved oxygen (Table A-5).

In 1975, mean chlorophyll a ranged from 1.8 to 11.3 µg/l with a lake wide mean of 4.5 ± 3.2 µg/l. Cheboygan and Alpena had elevated concentrations of 6.6 and 11.3 µg/l, respectively. The Saginaw Bay location was not included in the calculations of these means, because the three stations there were within the immediate influence of the river, as reflected by their chlorophyll a concentration of 60.5 ± 46.8 µg/l. The influence of sampling locations within the Bay on chlorophyll a concentration is indicated by the 1974 values which were exceptionally low compared to our 1975 data and that of other researchers (Smith 1977; IJC 1977). The 1974 stations were located in the upper middle and outer portion of the bay. Data from both years indicate significant enrichment at Alpena and Saginaw Bay. Enrichment at Alpena is primarily the result of discharges from the Abitibi Corporation, while the enrichment of Saginaw Bay is due to numerous point (e.g. Saginaw River) and non-point sources.

Heavy Metals in Water

Heavy metals were very low in Lake Huron waters during 1974 and 1975. In 1974, with the exception of Saginaw River, total arsenic, cadmium and mercury were at or just above their detection levels of 1.0, 2.0 and 0.2 µg/l, respectively. In 1975, arsenic and mercury concentrations were consistently just above the detection level (0.2 and 0.02 µg/l, respectively) at all locations but below the criteria to protect aquatic life. Cadmium concentrations were lowest in the northern portion of the lake and increased from Alpena south to Harbor Beach. At Lexington, the southern most location, cadmium returned to background levels. None of the values approached the lowest aquatic life criterion for cadmium of 0.4 µg/l.

Selenium was below the detection limit (1.0 µg/l at all stations in 1974, and was not analyzed during 1975.

Most total chromium levels were below detection (1.0 µg/l) with 2.0 µg/l being the highest concentration reported in 1974. In 1975, the detection level for total chromium was lowered to 0.3 µg/l, with all location means less than 1.0 µg/l, well below the 50 µg/l criterion for public drinking water, and 100 µg/l for aquatic life (U. S. EPA 1976).

Individual copper values ranged from below detection (1.0 µg/l) at Presque Isle and Alpena in the spring of 1974, to 28 µg/l at Tawas in the fall. Location means ranged from 1.0 µg/l at Lexington, to 13 µg/l at Tawas, with a lakewide annual mean of 3.6 ± 2.9 µg/l. There were no significant differences between locations or sampling periods. In 1975, location means ranged from 0.7 to 3.4 µg/l, with a lakewide mean of 1.6 ± 0.8. No values exceeded the criterion of 1000 µg/l for public drinking water (U. S. EPA 1976). Detour, Cheboygan and Tawas exceeded the recommended GLWQA 5.0 µg/l objective in the spring of 1974, as did Presque Isle in the fall of 1974; however, no annual means exceeded this objective in either 1974 or 1975, except at Tawas in 1974.

In 1974, means for iron ranged from 12 to 228 µg/l, with a lakewide average of 68 ± 63 µg/l. While no sampling period differences were found, significant iron differences occurred among locations, with Harbor Beach values being significantly higher than Harrisville, Tawas and Cheboygan. Individual samples were highly variable, but no location means exceeded the water quality criterion of 300 µg/l for iron in drinking water (U. S. EPA 1976). Collection methods partially account for the elevated values reported for Harbor Beach. During 1975, location means ranged from 8 to 24 µg/l with a lakewide average of 18 ± 6 µg/l.

Manganese was found above the detection limit (1.0 µg/l) in all Lake Huron samples during 1974 with location means ranging from 2 to 15 µg/l, and a lakewide mean of 5 ± 4 µg/l. The Alpena mean was significantly higher than that of Harrisville, but other location or sampling period differences were not significant. Individual samples at Alpena exceeded the 50 µg/l criterion for manganese in public water supply (U. S. EPA 1976). In 1975, manganese detection limits were reduced to 0.05 µg/l, with all location means less than 2.0 µg/l.

In 1974, lead was frequently below the detection limit (5.0 µg/l). Although location means ranged up to 8 µg/l, most were below detection. No statistical analysis was performed because of the lack of detectable values for lead. In 1975, lead detection levels were lowered to 0.2 µg/l, with location means ranging from 0.4 to 1.0 µg/l. All values during both years were much lower than the 20 µg/l GLWQA objective for Lake Huron.

Total nickel levels (5 µg/l) were detectable in only five individual samples taken during 1974: three at Harbor Beach, and one each at Alpena and Presque Isle. No values exceeded the 25 µg/l criterion for the protection of aquatic life (GLWQA 1978). In 1975, location means ranged from 0.8 to 1.4 µg/l total nickel, indicating no excessive nickel levels in Lake Huron waters.

Zinc concentrations were variable in 1974, with location means ranging from 5 µg/l at Harrisville to 29 µg/l at Detour in the fall, with a lakewide average of 10 ± 6 μg/l. The Detour mean approached the 30 μg/l criterion for zinc (IJC, 1977). There is no known source of zinc at this location. In 1975, zinc concentrations were substantially lower, with means ranging from below 1.3 to 4.9 μg/l and a lakewide average of 2.5 ± 1.0 μg/l. There were no elevated values at Detour in 1975, indicating no long-term sources at that location.

Organic Chemicals in Water

In 1974, organic chemicals in Lake Huron were at very low levels or below detection levels. DDD and DDE were below detection levels (0.001 μg/l) at all locations. DDT was detected in five samples, ranging from 0.002 to 0.004 μg/l. Detour, Cheboygan, and Presque Isle each had one sample with measurable DDT levels, and Lexington had two. Polychlorinated biphenyls (PCB, Arochlor 1242, 1254 and 1260) were found above detection levels of 0.01 μg/l in single samples at Alpena (0.02 μg/l) and Harrisville (0.08 μg/l). No known sources of PCB occur at these locations, although both areas have industries which used PCB in the past. However, the concentrations of PCB were below detection in samples taken prior to this lake survey in these industrial effluents.

Dieldrin was above the detection limit (0.001 μg/l) in only one sample from Detour, and diethylhexel phthalate was found above detection levels (1.0 μg/l) at Presque Isle (2.6 μg/l), Harrisville (2.0 μg/l) and Saginaw Bay (1.4 μg/l). Phthalates are used as plasticizers in innumerable products, and samples may have been contaminated by collecting and processing equipment. Also, low levels of phthalates are relatively common in wastewater discharges.

In 1975, all concentrations of organics in water were reported as below the limits of detection due to interference during the laboratory analysis, as explained in the Lake Superior section of this report.

Radioactivity

Samples for radioactive analysis were collected only in the spring and fall of 1974. Based on the gamma scan, zinc 65, zirconium 95, niobium 95, cesium 137, cobalt 60 and manganese 54 were all below the minimum detectable activity levels of 30, 13, 13, 15, 15 and 13 pCi/l, respectively. Gross beta activity was also low ranging from one to five pCi/l with a lakewide average of 2.7 pCi/l.

Sediment Chemistry

In 1974, the nearshore sediments at background locations in Lake Huron had low levels of pesticides, PCB, metals, nutrients and COD. However, measurable total DDT residues were found in samples at two background areas, Presque Isle (16.3 μg/kg) and Harrisville (3.0 μg/kg). Lexington exceeded EPA dredge spoil criteria for arsenic but this result was based only on one sample.

Impacted areas generally had higher concentrations of all sediment contaminants than background areas. However, mercury, cadmium and selenium were below levels of detection, and lead was within background levels at all locations.

Cheboygan sediments averaged 72 μg/kg total DDT. Cheboygan also exceeded the EPA dredge spoil criteria for oils and grease at two stations, and TKN and zinc at one station.

The Alpena stations had total DDT concentrations ranging from 3.9 to 30.7 μg/kg and exceeded EPA dredge spoil criteria for TKN, oils and grease, and arsenic.

Detectable levels of PCB were found only in the sediments at Harbor Beach (18 to 27 μg/kg) where these values interfered with the analysis of pesticides. Total Kjeldahl nitrogen, COD, oil and grease, zinc, arsenic, nickel and iron in the Harbor Beach sediments were above the EPA dredge spoil criteria. There were also elevated concentrations of copper, manganese and chromium. These heavy metal concentrations have been attributed to Hercules, Incorporated, whose sludge contained these metals.

In 1975, location means for sediments sampled at Calcite and the open waters of Saginaw Bay were within EPA dredge spoil criteria. However, the sediments near the mouth of the Saginaw River would be classified as grossly contaminated.

Bacteria

The bacteriological quality of the nearshore waters of Lake Huron was high with most locations sampled relatively free from fecal contamination, except in the near to shore areas surrounding municipal and industrial discharges.

Bacterial densities at the background locations in the spring (July) and fall of 1974 were generally below detection levels except at the two southern most locations, Harrisville and Lexington. Geometric mean total coliform counts at these two locations in the fall ranged from 141 to 741 organisms/100 ml (Table 13). Similar increases in fecal coliform or fecal strepococci were not observed.

Elevated bacterial densities were observed at all impacted locations. Bacterial densities in Saginaw Bay were elevated only during the fall of 1974 with densities below detection levels except for total coliforms at station 1 (Table 13).

Geometric means for replicated samples from river-mouth stations exceeded the Michigan criterion for fecal coliforms at Cheboygan and Alpena during the 1974 spring sampling period (Table 13).

Alpena was the only location with consistently elevated total coliform counts during both 1974 sampling periods. Spring counts exceeded 1000/100 ml as far as 1000-m southeast of the river mouth, and counts greater than 500/100 ml were found at stations 2000-m from the river mouth. The fall cruise showed a similar offshore gradient but the mean coliform count found in the

Table 1[illegible]. Geometric mean bacterial densities in nearshore Lake Huron, 1974.
(Expressed as organisms/100 ml).

Location	Station	Total Coliform		Fecal Coliform		Fecal Streptococci	
		Spring	Fall	Spring	Fall	Spring	Fall
Detour*	1	141	< 100	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	< 100	< 10	< 10	< 10	< 10
Cheboygan	1	6,148	648	455	40	35	< 10
	2	141	< 100	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	4	< 100	< 100	< 10	< 10	< 10	< 10
	5	141	< 100	< 10	< 10	< 10	< 10
	6	< 100	141	< 10	< 10	< 10	< 10
	7	< 100	< 100	< 10	< 10	< 10	< 10
Presque Isle*	1	< 100	< 100	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	< 100	14	< 10	< 10	< 10
Alpena	1	4,141	15,875	288	120	30	< 10
	2	400	346	25	14	< 10	< 10
	3	2,020	487	26	< 10	14	< 10
	4	900	1,264	30	< 10	< 10	< 10
	5	224	424	< 10	14	< 10	< 10
	6	671	200	26	< 10	< 10	< 10
	7	< 100	245	< 10	< 10	< 10	< 10
Harrisville*	1	< 100	141	< 10	< 10	< 10	< 10
	3	< 100	519	< 10	< 10	< 10	< 10
	6	< 100	245	< 10	< 10	< 10	< 10
Tawas	1	424	3,429	22	240	17	14
	2	< 100	905	< 10	< 10	< 10	< 10
	3	< 100	< 100	< 10	< 10	75	< 10
	4	< 100	< 100	< 10	< 10	< 10	17
	5	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	< 100	< 10	< 10	< 10	< 10
	7	< 100	< 100	< 10	< 10	< 10	< 10

continued

Table 13. (continued)

Location	Station	Total Coliform		Fecal Coliform		Fecal Streptococci	
		Spring	Fall	Spring	Fall	Spring	Fall
Saginaw Bay	1		141		< 10		< 10
	2		< 100		< 10		< 10
	3		< 100		< 10		< 10
	4		< 100		< 10		< 10
Harbor Beach	1	4,877	346	49	< 10	49	< 10
	2	316	< 100	< 10	< 10	< 10	< 10
	3	741	245	< 10	< 10	< 10	< 10
	4	387	346	< 10	< 10	< 10	< 10
	5	< 100	< 100	< 10	< 10	< 10	< 10
	6	< 100	141	< 10	14	< 10	< 10
	7	200	632	25	14	< 10	< 10
Lexington*	1	< 100	173	< 10	< 10	< 10	< 10
	3	< 100	600	< 10	< 10	< 10	< 10
	6	223	741	< 10	< 10	< 10	17

* Background location

river mouth exceeded 15,000/100 ml (Table 9). Fecal coliform counts were above 200/100 ml only in the spring and fecal streptococci were not above 30 counts/100 ml at any time.

Phytoplankton

Few studies of the phytoplankton communities in Lake Huron have been undertaken. In a 1971 survey, Vollenweider *et al*. (1974) noted low biomass in the offshore stations with the diatoms *Cyclotella*, *Tabellaria*, *Stephanodiscus*, *Melosira*, and *Synedra* dominating the community. At times, various phytoflagellates and cryptomonads, including *Cryptomonas erosa* and *Rhodomonas minuta*, accounted for up to 20 percent of the biomass.

Schelski *et al*. (1974) described phytoplankton assemblages in western Lake Huron. They found populations north of Saginaw Bay were dominated by diatoms including *Cyclotella stelligera*, *C. michiganiana*, *C. comta*, *C. operculata*, *C. ocellata*, *Fragillaria crotonensis*, *Rhizosolenia gracilis* and *Asterionella formosa* while only *C. stelligera* and *C. michiganiana* were dominant south of Saginaw Bay.

The phytoplankton community in Michigan's nearshore waters of Lake Huron were sampled during spring and fall of 1974. The species list for Lake Huron included approximately 300 phytoplankton taxa with diatoms generally dominant (Table A-15). The diatoms, primarily *Tabellaria fenestrata*, *Fragillaria crotonensis*, *Cyclotella glomerata*, *C. comensis*, and *Asterionella formosa* were the dominant algal group during June. Abundant species other than diatoms included *Rhodomonas minuta*, *Dinobryon* sp., *Chrysosphaerella longispina* and *Aphanocapsa delicatissima*.

The phytoplankton data from Alpena and Lexington indicated the presence of nutrient enrichment at these locations (Figures 8 and 9). Alpena had very high phytoplankton standing crops in the spring, about 4 times the lakewide mean, with samples dominated by a large bloom of the blue-green algae *Dactylococcopsis fascicularis* (Table A-16). The total numbers of algae at Alpena were also above the lakewide mean in September, when collections were dominated by the eutrophic diatoms, *Melosira granulata* and *Fragillaria crotonensis*, although there was a shift back to more oligotrophic forms, especially *Tabellaria fensestrata* and *Cyclotella glomerata*.

Lexington would be classified as eutrophic based on the high standing crop of phytoplankton. The fall samples at this location were dominated by *Fragillaria crotonensis* and *Cyclotella comensis*, with total numbers about twice the lakewide mean.

Algal abundance at the northern Lake Huron stations were one-third to one-half the lakewide mean. There appeared to be an overall north to south increase in algal abundance in Lake Huron, but this trend was masked by within-location variability.

Statistical comparisons made between the composite and the 5-meter grab samples indicated no significant differences ($P<0.05$) between either species

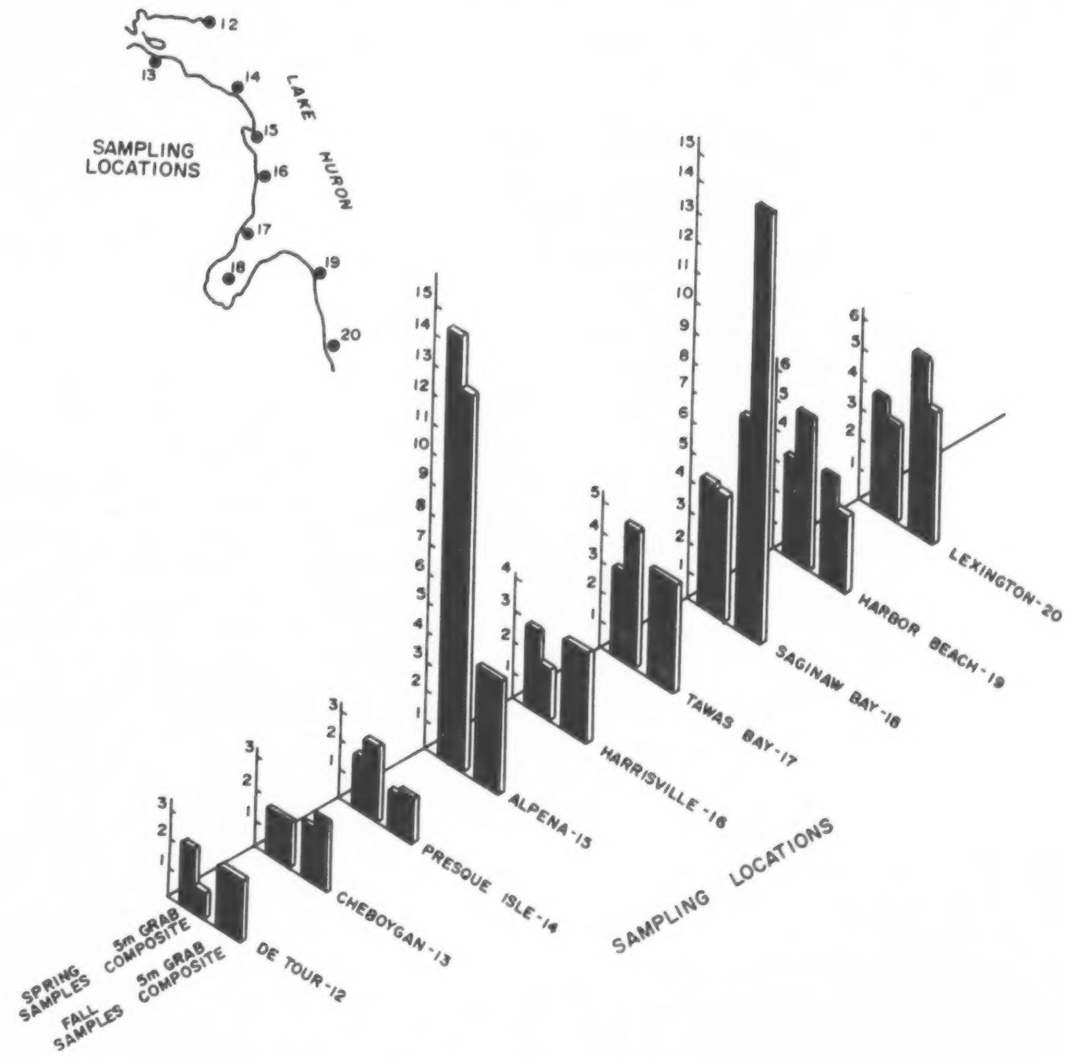

Figure 8 Nearshore phytoplankton standing crop, Lake Huron, 1974

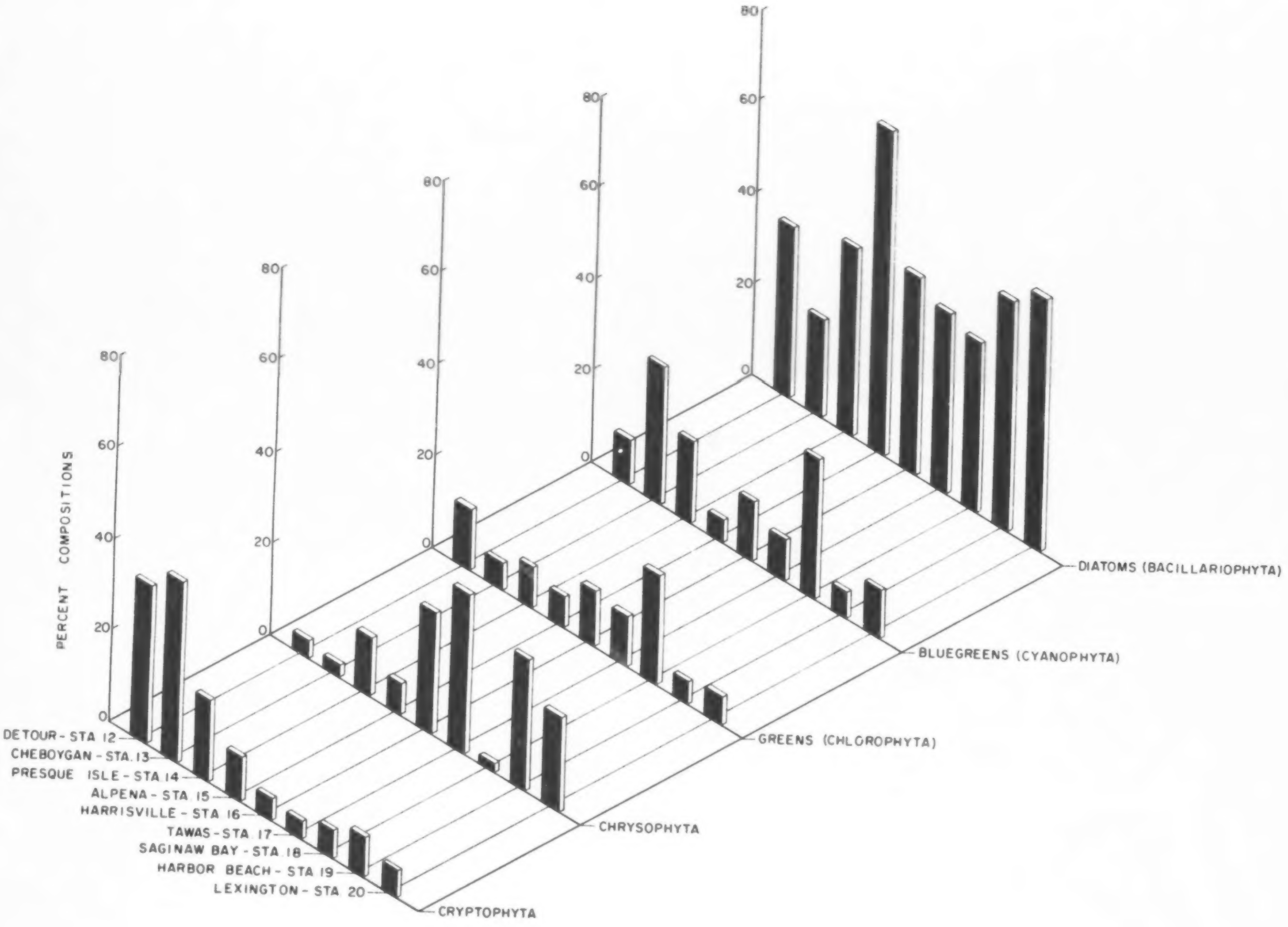

Figure 9a Percent composition of major nearshore algal groups in the spring, Lake Huron 1974

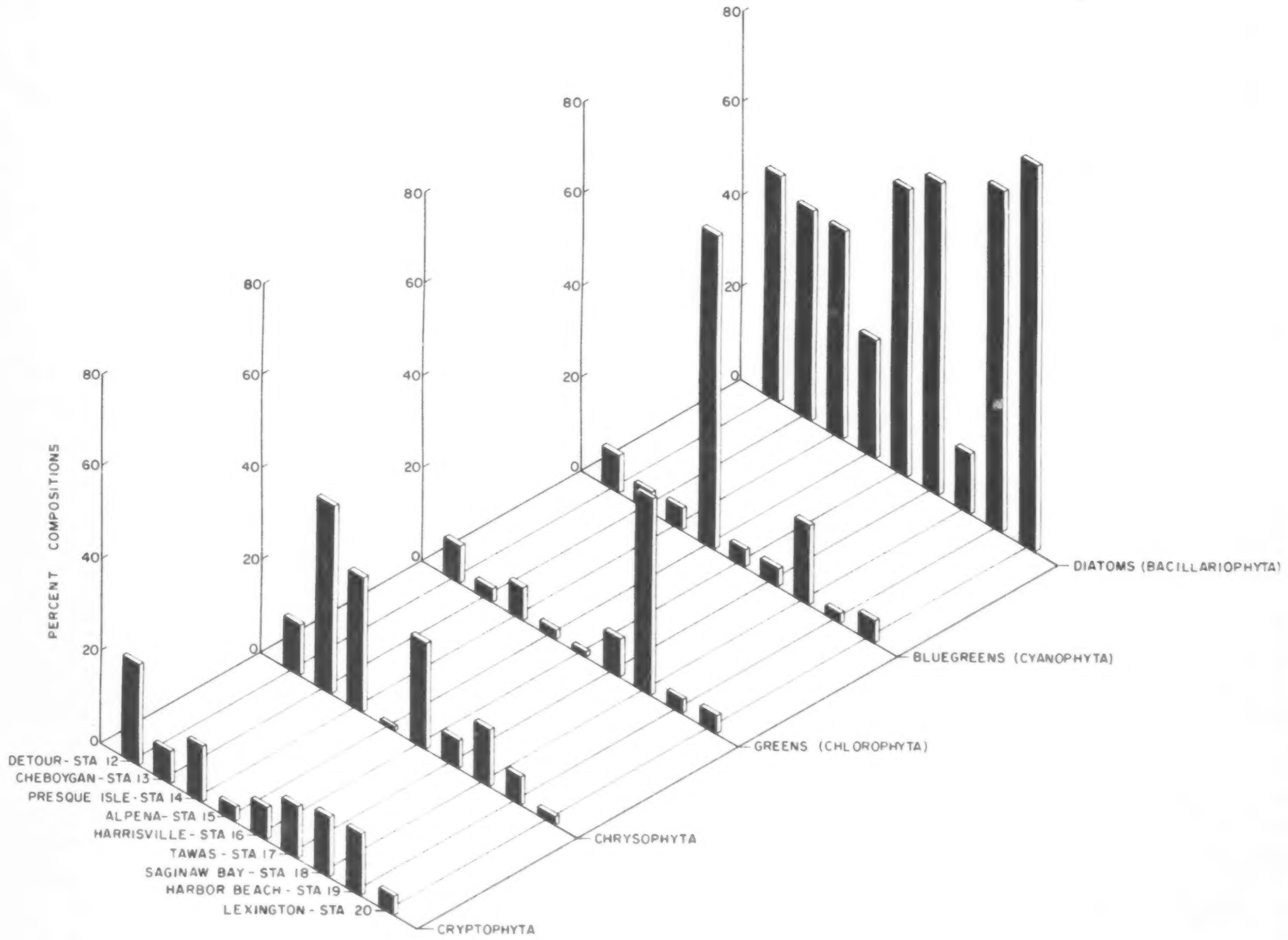

Figure 9b Percent composition of major nearshore algal groups in the fall, Lake Huron 1974

found, or mean number of algal units. Most locations showed no major species changes with depth. Generally, from two to five species were abundant at a station with only relatively minor ranking changes, although Saginaw Bay and Tawas varied from this pattern. At Tawas, Ulothrix, a green alga indicative of eutrophic conditions, was abundant close to shore (station 1), but not at stations further offshore. In Saginaw Bay, a decrease occurred from the inner to the outer bay in the blue-green alga, Oscillatoria, and the green alga, Ulothrix. Nutrient dilution and distance from shore appears to have caused species shifts at these impacted locations.

Zooplankton

Only a few studies have been published describing the populations of Lake Huron zooplankton. Schelske and Roth (1973) found Diaptomus, Bosmina, and Cyclops to be most abundant in Lake Huron north of Saginaw Bay, with many genera represented. Patalas (1972) found 23 crustacean taxa with Cyclops bicuspidatus thomasi, Diaptomus sicilis, D. ashlandi and D. minutus the most abundant copepods, while Holopedium gibberum and Bosmina longirostris were the most abundant cladocerans. Nauwerck (1972) reported approximately 30 species of rotifers from Lake Huron with Kellicottia, Notholca, Synchaeta, Polyarthra, Conochilus, Keratella, and Gastropus stylifer common in the open lake. Watson (1974) reported eighteen common species of rotifers in Lake Huron.

Zooplankton were collected in the spring and fall of 1974. In the spring, mean zooplankton densities averaged 13,444 ± 14,331 organisms/m^3. In the fall, densities decreased to 4545 ± 2164 organisms/m^3, but no statistically significant differences were found between seasons. This pattern was similar at both background and impacted locations, and although impacted locations appeared to have greater numbers, no significant differences ($P<0.05$) were found between locations. The ratio of calanoid copepods to cyclopoids and caldocerans has been related to nutrient enrichment in the Great Lakes (Patalas, 1972) with a large ratio (a large percentage of calanoid copepods) reflecting low nutrients. This ratio was over 0.65 during the spring at Detour, Presque Isle and Harrisville, while the other locations had ratios below 0.55. In the fall, Cheboygan and Alpena had ratios below 0.30, indicating significantly enriched conditions.

The most abundant species were the cladoceran Bosmina longirostris, the calanoid copepods Diaptomus oregonensis and D. minutus and the cyclopoid copepod Cyclops biscuspidatus thomasi (Tables A-17 and A-18). In addition, Diaptomus sicilis, Epischura lacustris and Daphnia retrocurva were present at most locations and occasionally reached relatively high numbers. Holopedium gibberum was found at all locations in the fall (ranging from 9 to 17/m^3) but occurred only atDetour and Presque Isle in the spring (7/m^3 and 9/m^3, respectively). Daphnia retrocurva was present at all locations in the fall and at 7 of 9 locations in the spring.

Low numbers of Ceriodaphnia lacustris, generally considered a summer plankter, were found during June at Lexington, and in the fall at Cheboygan, Alpena and Tawas City. While not abundant, it appears to be widespread in Lake Huron at locations having extensive reaches of shallow water. Other crustacean zooplankton numbers were also generally higher at station 1.

Daphnia galeata mendotae and Bosmina coregoni were found only at station 1 in the fall. Diaptomus ashlandi, however, was not found at station 1 at any location.

Eight genera of rotifers were identified with Keratella, Polyarthra, Asplanchna, and Filinia abundant at all locations in all samples. Another commonly occurring form, Gastropus, was found at 3 of 9 locations in spring, and 2 of 9 in the fall, but no location had Gastropus during both sampling periods. The total numbers of rotifers varied considerably, from 381/m³ at Detour, to 9494/m³ at Harbor Beach. There were no significant differences between spring and fall abundances. A significant difference was noted between rotifer densities at station 1 (nearest to shore or the river mouth) and the other stations further offshore. This difference occurred even when no river was present, such as at Presque Isle, where the mean for station 1 was 2822/m³ while the mean was 661/m³ for stations further offshore. Since no difference in community structure was apparent at the generic level, the shallow nearshore areas appear to provide a more productive habitat for rotifers.

Benthic Macroinvertebrates

During the past two decades, several authors have reported on the benthic macroinvertebrate communities in Lake Huron. Significant accounts of the communities in the main basin are those of Teter (1960), Schuytema and Powers (1966), Schelske and Roth (1973), Shrivastava (1974), and Mozley (1975). Schneider et al. (1969) surveyed the benthic community in Saginaw Bay, and Brinkhurst (1969) reported on oligochaetes from the same samples. Quantitative comparisons with older studies may not be valid due to dissimilarity of collection techniques. In earlier studies, usually only one sample per station was collected with no estimate of variance given. For this reason, results from older studies in the vicinity of stations sampled in 1974 and 1975 were only qualitatively compared.

Cook and Johnson's (1974) review of the benthic literature showed that the open waters of Lake Huron are dominated by Pontoporeia affinis, oligochaetes, chironomids and sphaeriids. Mozley (1975) reported that P. affinis, Stylodrilus heringianus and Enchytraeidae were the most numerous taxa at depths greater than 30 m with Peloscolex variegatus and Heterotrissocladius cf. subpilosus also typical members of the profundal benthic fauna.

The taxonomy of the benthic communities of the Great Lakes is incomplete and knowledge of the ecology of many important species is limited, preventing the development of a complete list of indicator species. Recent papers discussing nearctic chironomids as indicators of lake typology may clarify the present chironomid lake classification scheme (Saether, 1975a, Saether, 1975b).

In 1974, Michigan's nearshore waters of Lake Huron were sampled at four background locations (Detour, Presque Isle, Harrisville and Lexington) and four impacted locations (Cheboygan Alpena, Tawas and Harbor Beach). During 1975, an additional background location (Calcite) was evaluated, and two impacted locations (Alpena, Harbor Beach) were re-evaluated (Figure 10).

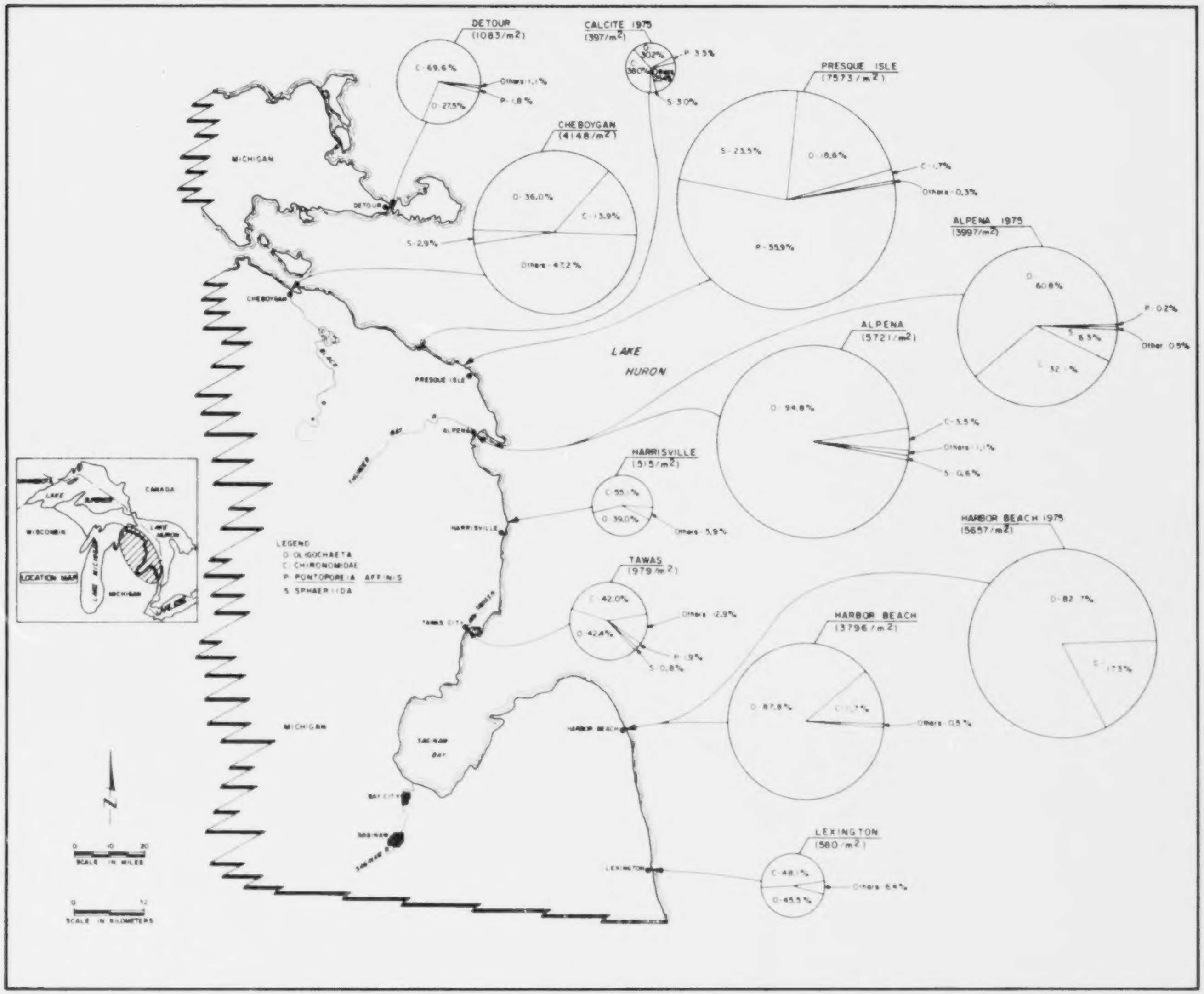
DETOUR
(1083/m2)
C-69.6%
Others-1.1%
P-1.8%
O-27.5%
CALCITE 1975
(397/m2)
O 30.2%
C 38.0%
Others 25.4%
P 3.3%
S 3.0%
PRESQUE ISLE
(7573/m2)
S-23.5%
O-18.6%
C-1.7%
Others-0.3%
P-55.9%
CHEBOYGAN
(4148/m2)
O-36.0%
C-13.9%
S-2.9%
Others-47.2%
ALPENA 1975
(3997/m2)
O 60.8%
P 0.2%
S 6.5%
Other 0.5%
C 32.1%
ALPENA
(5721/m2)
O-94.8%
C-3.5%
Others-1.1%
S-0.6%
HARRISVILLE
(515/m2)
C-55.1%
O-39.0%
Others-5.9%
TAWAS
(979/m2)
C-42.0%
O-42.4%
Others-12.9%
P-1.9%
S-0.8%
HARBOR BEACH 1975
(5657/m2)
O-82.7%
C-17.3%
HARBOR BEACH
(3796/m2)
O-87.8%
C-11.7%
Others-0.5%
LEXINGTON
(580/m2)
C-48.1%
O-45.5%
Others-6.4%
LAKE HURON
MICHIGAN
DETOUR
CHEBOYGAN
PRESQUE ISLE
ALPENA
THUNDER BAY
HARRISVILLE
TAWAS CITY
SAGINAW BAY
BAY CITY
SAGINAW
SAGINAW R.
HARBOR BEACH
LEXINGTON
LEGEND
O-OLIGOCHAETA
C-CHIRONOMIDAE
P-PONTOPOREIA AFFINIS
S-SPHAERIIDA
LOCATION MAP
CANADA
WISCONSIN
LAKE SUPERIOR
LAKE HURON
LAKE MICHIGAN
N
0 10 20
SCALE IN MILES
0 12
SCALE IN KILOMETERS

Figure 10 Percent composition and density of major benthic macroinvertebrate taxonomic groups in nearshore Lake Huron, 1974 and 1975

Total benthic communities at the background locations ranged from 397 organisms/m^2 at Calcite, to 7573 organisms/m^2 at Presque Isle. The communities were dominated by chironomids and oligochaetes, except at Presque Isle where the total population of 7573 organisms/m^2 was dominated by *Pontoporeia affinis* and sphaeriids (Table 14).

The sample at Detour, collected at 23-m, had a community of 1083 organisms/m^2, 81 percent of which were the oligotrophic indicators *Stylodrilus heringianus* and *Heterotrissocladius* cf. *changi*. Other abundant species included *Monodiamesa* cf. *tuberculata*, *Protanypus*, *Micropsectra*, *Paracladopelma* cf. *camplolabis* and *Tanytarsus* (Tables A-19 and A-20).

The benthic collections at Presque Isle were unique because of an exceptionally high density of organisms (7573 organisms/m^2). *Pontoporeia affinis* and *Pisidium* formed 79 percent (6011 organisms/m^2) of the total population. The samples were collected from depths 9 to 27-m deeper than the average depth at other locations, which may account for the high densities. Teter, (1960) and Schelske and Roth (1973) found similar densities of *Pontoporeia affinis* in profundal samples with low numbers of sphaeriids. Shrivastava (1974) and Schuytema and Powers (1966) indicated that high mean densities of *P. affinis* (600-800/m^2) occurred between 20 and 40-m which includes the sample depth at Presque Isle (33-m).

Chironomids and oligochaetes at Presque Isle formed only 1.7 and 18.6 percent of the total population, respectively. The oligotrophic indicator forms, *Stytodrilus heringianus* and *Heterotrissocladius* cf. *changi*, dominated these groups but the more pollution-tolerant tubificids, *Limnodrilus hoffmeisteri* and *Potamothrix vejdovskyi*, were also present.

The total benthic communities at the other two background locations, Harrisville and Lexington, were 515 and 580 organisms/m^2, respectively, with communities dominated by nearly equal numbers of chironomids and oligochaetes. The oligochaetes had a low diversity of species with *Stylodrilus heringianus* abundant at both locations, but dominant only at Harrisville. *Piquetiella michiganensis* was dominant at Lexington. Unidentifiable immature tubificids and *Potamothrix vejdovskyi* were also abundant at both locations.

The chironomid community at Harrisville was composed primarily of the pollution-intolerant forms *Heterotrissocladius* cf. *changi*, *Paracladopelma undine*, *Potthastia* cf. *longimanus*, *Tanytarsus*, and *Micropsectra*, while the chrionomid fauna at Lexington consisted of a number of pollution-tolerant forms, *Chironomus anthracinus* gr., *Pseudochironomus* and *Procladius*. The primary oligotrophic indicator species were not found at Lexington.

Calcite, located northwest of the 1974 sampling location at Presque Isle, was a background location in Lake Huron during 1975. The total benthic population at Calcite averaged 397 organisms/m^2 and consisted of similar numbers of oligochaetes and chironomids. *Stylodrilus heringianus* was the dominant oligochaete (70 organisms/m^2). Of the eight chironomid taxa found, *Parakiefferiella* and *Cricotopus* were the most abundant (32 and 19/m^2, respectively) with *Heterotrissocladius* cf. *changi* present in low numbers (6/m^2) The amphipod *Pontoporeia affinis* (6/m^2) was also found.

Table 14. Mean numbers of benthic macroinvertebrate major taxonomic groups at selected locations in nearshore Lake Huron, 1974 and 1975. Entries are expressed as organisms/m^2 unless otherwise noted.

	Number of Stations	Number of Taxa	Total Number/Station			P. affinis	Oligochaetes	Chironomids	Sphaeriids	"Other" taxa
			Mean	Standard Deviation	Range					
Background										
DeTour	1	12	1083	---	--- - ---	19	298	754	0	12
Calcite	1	21	387	---	--- - ---	13	120	151	12	101
Presque Isle	1	14	7573	---	--- - ---	4231	1412	132	1780	18
Harrisville	1	21	515	---	--- - ---	0	201	284	0	30
Lexington	1	24	580	---	--- - ---	0	264	279	0	37
Impacted										
Cheboygan	6	81	4148	2722	833 - 9085	0	1497	575	119	1957
Alpena - 1974	10	55	5721	3468	2223 -12323	1	5423	199	34	65
- 1975	6	68	3997	2097	1610 - 7731	8	2429	1285	253	21
Harbor Beach - 1974	8	36	3796	2214	486 - 7189	0	3334	375	0	19
- 1975	3	16	5657	6506	44 -12788	0	4679	978	0	0
Tawas	7	56	979	820	201 - 2684	2	415	411	8	143

The four impacted locations, Cheboygan, Alpena, Harbor Beach and Tawas, had high benthic populations (4418, 5721, 3796 and 979 organisms/m^2, respectively). The mean total abundance of benthic organisms at the four impacted locations was 3763 organisms/m^2. Mean densities of oligochaetes, chironomids, P. affinis, sphaeriids and other taxa were 2666, 391, 4, 161 and 541 organisms/m^2, respectively. Although differences occured in local benthic assemblages, the high numbers of tubificids found at each impacted location indicated nutrient enrichment.

Fifty-three percent of the benthic fauna at Cheboygan was comprised of oligochaetes, chironomids and sphaeriids, (36.1, 13.0 and 3.0 percent, respectively). The remaining forty-seven percent consisted primarily of isopods, Asellus and Lirceus, and amphipods, Gammarus and Hyalella azteca. These four taxa accounted for 37.2 percent of the total benthic community. Lirceus and H. azteca were the most abundant of this group, reaching maximum densities of 2552 and 2413/m^2, respectively, at station 6 in 1974. The amphipod, Pontoporeia affinis, was not found at Cheboygan.

The oligochaete community at Cheboygan contained 22 species of which 13 were tubificids. Maximum oligochaete densities (3437/m^2) were found at the mouth of the harbor, indicating significant enrichment from the river. Unidentifiable immature tubificids dominated the oligochaete numbers, accounting for 60 percent of the total. Significant differences were apparent between stations with the pollution-tolerant oligochaetes, Aulodrilus pluriseta, Limnodrilus cervix and L. hoffmeisteri dominant only at stations 1 and 3. both located near the mouth of the Cheboygan River and the offshore stations.

The chironomid fauna at Cheboygan was highly diverse with 31 taxa represented. The abundant species were primarily pollution-tolerant forms found near the river mouth, including Procladius, Chironomus anthracinus gr., Cryptochironomus, Microtendipes, Phaenopsectra (Tribelos), Polypedilum scalaenum gr., Pseudochironomus, and Tanytarsus. The pollution-intolerant forms Heterotrissocladius, Monodiamesa cf. depectinata, Potthastia cf. longimanus and Paracladopelma were present in very low numbers, primarily at stations farther from the river mouth.

Both the presence of pollution-tolerant forms in high numbers and the abundance of isopods and amphipods at the harbor mouth indicate a high degree of organic enrichment at Cheboygan.

Tawas had a diverse assemblage of oligochaetes (19 species) and chironomids (27 species). The oligochaete community was dominated by immature tubificids which made up greater than 40 percent of the community, Peloscolex ferox, a species tolerant of moderate pollution, and Stylodrilus heringianus, generally considered an oligotrophic species, were also dominant. Peloscolex ferox, was common at all stations, and the dominant species at station 1, whereas Stylodrilus heringianus was dominant only at station 7, further offshore.

The most abundant chironomids found at Tawas, Pseudochironomus and Cryptochironomus gr., are considered pollution-tolerant. The oligotrophic forms Heterotrissocladius and Paracladopelma were found in relatively low numbers only at stations furthest from shore indicating water quality improvement with distance from the river mouth. The diversity and predominance of mesotrophic and eutrophic benthic forms demonstrates the influence of Saginaw Bay on the water quality at Tawas.

Historical data for Thunder Bay at Alpena reflect changes occurring in the nearshore waters of Lake Huron as a result of organic enrichment. In 1957, a highly diversified benthic community containing many pollution-intolerant forms with 12,260 organisms/m^2, was found. By 1965, this community had been almost exclusively replaced by one of pollution-tolerant forms with only 2260 organisms/m^2 (MWRC, 1965a). In 1974, the mean benthic densities ranged from 2223 to 12,333 organisms/m^2, with an overall average of 5721 organisms/m^2. In 1975, mean densities ranged from 1610 to 7731 organisms/m^2. Oligochaetes comprised 72 percent of the total population during 1957, 89 percent during 1965, 95 percent during 1974 and in 1975, dropped to 60 percent (Figure 11). In 1974, maximum oligochaete densities of more than 12,000/m^2 were found near the mouth of the Thunder Bay River, with unidentifiable immature tubificids accounting for 71 percent of oligochaete numbers. The most abundant of the 23 oligochaete species found during both years were *Nais*, *Aulodrilus americanus*, *A. piqueti*, *A. pluriseta*, *Limnodrilus hoffmeisteri*, *Peloscolex ferox*, *P. multisetosus* and *Potamothrix vejdovskyi*, all considered pollution-tolerant organisms.

Chironomids remained relatively constant at 3 to 5 percent, during the past 18 years, until in 1975 they increased to 33 percent. In 1975, these chironomids considered primarily of the pollution-tolerant forms, *Cryptochironomus*, *Procladius*, *Tanytarsus*, and *Harnishia*. In 1974, chironomid species consisted of *Procladius*, *Chironomus anthracinus* gr., *Chironomus fluviatilis* gr., *Chironomus plumosus*, *Cryptochironomus* and *Tanytarsus*.

Sphaeriids which accounted for 18 percent of the total population during 1957, decreased to 2, 1 and 6 percent during 1965, 1974 and 1975, respectively. The percentage of "other taxa" showed a similar decrease from 5 to 1 percent since 1957. The oligotrophic indicator species *Pontoporeia affinis*, *Stylodrilus heringianus* and *Heterotrissocladius* were present in very low numbers in 1974, and then only at the outermost stations. *S. heringianus* was found at very low numbers only at two intermediate stations in 1975.

Harbor Beach was the only impacted location without a major river discharge, but the harbor was confined by an extensive breakwall. In 1974, the benthic community was sampled at seven stations within the harbor and one station about 350 meters west of the main entrance; in 1975, samples were taken at two stations inside the harbor and one outside the harbor.

In 1974 and 1975 benthic communities were dominated by oligochaetes (87.8 and 86 percent, respectively), with the pollution-tolerant tubificids, *Limnodrilus cervix*, *L. maumeensis*, and *L. hoffmeisteri* abundant. The pollution-tolerant chironomids, *Chironomus anthracinus* and *Chironomus plumosus* gr. were the most abundant midges.

In 1974, benthic densities at stations within the harbor ranged from 1973/m^2 to 7189/m^2, while densities outside the harbor were only 386 organisms/m^2. Although the station further offshore was also dominated by pollution-tolerant forms and would be classified as mesotrophic, the low populations and the limited

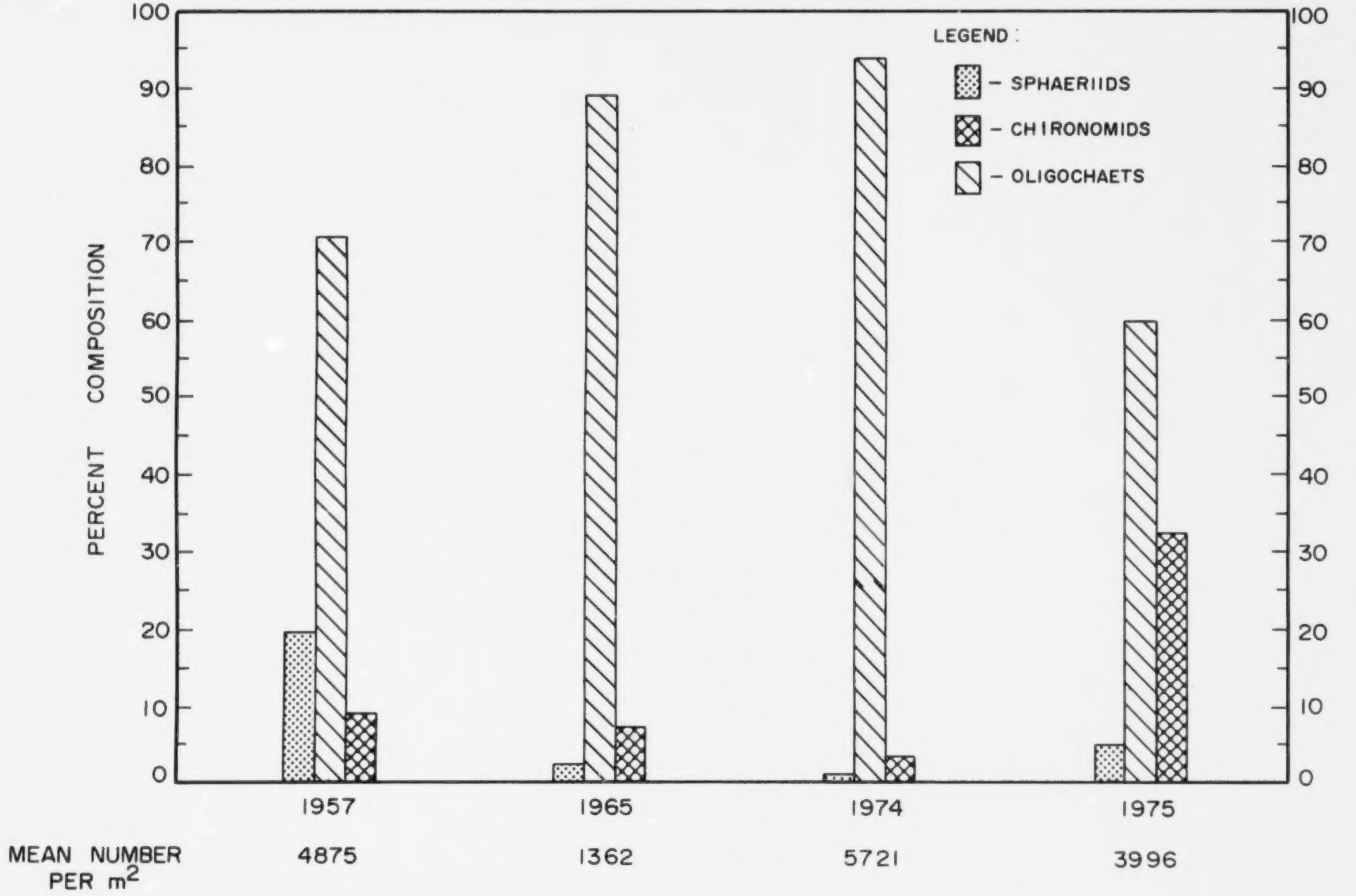

Figure 11 Percent composition of the major groups of benthic macroinvertebrates at Thunder Bay, Lake Huron, 1957 to 1975.

presence Stylodrilus heringianus, Peloscolex variegatus and Paracladopelma undine suggest improved water quality outside the harbor.

The Harbor Beach total communities showed no consistent pattern based on 1958, 1965, 1974 and 1975 samples, with 5343, 989, 3796 and 5657 organisms/m^2, respectively. The percentages of oligochaetes and chironomids in 1958 and 1974-5 were similar, 86 and 88 percent for oligochaetes, and 13 and 12 percent for chironomids. The 1965 survey had 77 percent oligochaetes and 22 percent chironomids (MWRC, 1965b). Pontoporeia affinis was absent, and sphaeriids and "other" taxa never exceeded 1 percent of the total population during any of the surveys.

The 1965 report concluded that water quality had decreased since 1958 even though there was a decrease in the percentage of oligochaetes (MWRC, 1965b). Based on the 1974 and 1975 results there appears to have been little change in the Harbor Beach benthic community since the 1965 study.

Contaminants in Fish

Heavy metal concentrations were generally very low in all areas of Lake Huron for all species of fish. No values exceeded the CFDD or new U.S. FDA tolerance limits. The only metal to approach these levels in 1974 samples was mercury, while all other metal concentrations were less than 10 percent of the tolerance limits. The highest mean mercury values were in yellow perch at all locations (Table 15) with the maximum individual mercury value of 0.49 mg/kg in a yellow perch from Hammond Bay.

All the metal levels in yellow perch during 1974 were low. Mercury ranged from 0.18 to 0.40 mg/kg with mean values for Thunder Bay and Tawas Bay of 0.26 ± 0.04 mg/kg and 0.27 ± 0.03 mg/kg, respectively. Values for Harbor Beach and Lexington were slightly higher (0.33 and 0.34 mg/kg, respectively). Areas south of Saginaw Bay appeared to have slightly higher mercury values than areas to the north, but no significant differences were found for mercury concentrations in yellow perch or whitefish.

Pesticides and other organic contaminants in all species were generally low (Table 16). In 1974 chlordane, lindane, methoxychlor, hexachlorobenzene, hexachlorbutadiene, dibutyl-n-phthalate, diethylhexylphthalate and polybrominated biphenyl were not detectable in any fish analyzed at detection levels shown in Table 2.

Concentrations of dieldrin were well below the U.S. FDA action level in all samples during 1974 and 1975. There were no significant location differences in dieldrin concentrations for any of the fish tested.

Total DDT during 1974 and 1975 were generally found above detection levels with the highest location mean concentration (0.97 mg/kg) occurring in a chinook salmon from Alpena. The lowest location mean was in yellow perch from Hammond Bay, where total DDT was not detected in any sample. The salmonids, including whitefish, had mean levels greater than 0.2 mg/kg, while percids (yellow perch and walleye) means were below 0.07 mg/kg.

Table 15. Mean concentrations of selected metal contaminants in Lake Huron fish, 1974 and 1975. Entries expressed as mg/kg wet weight basis for edible fillets.

1974

Location	Fish Species	Mercury mg/kg	Copper mg/kg	Zinc mg/kg	Lead mg/kg	Cadmium mg/kg
Hammond Bay	Brown trout	0.13	0.74	3.46	0.11	0.03
	Yellow perch	0.31	0.56	4.60	0.26	0.10
	Rainbow trout	0.10	0.61	3.78	0.07	0.03
	Walleye	0.17	0.28	3.80	0.23	0.30
	Whitefish	0.04	0.64	3.59	0.71	ND
Alpena	Brown trout	0.13	0.33	2.90	0.10	0.01
	Chinook salmon	0.22	----	----	----	----
	Yellow perch	0.15	0.37	4.69	0.18	0.03
	Whitefish	0.03	----	----	----	----
Tawas	Whitefish	0.03	----	----	----	----
Harbor Beach	Yellow perch	0.34	0.31	7.70	0.40	0.03
Lexington	Yellow perch	0.33	0.24	7.12	0.32	0.03
		1975				
Hammond Bay	Lake trout	0.15	----	----	----	----
Alpena	Yellow perch	0.26	0.29	8.12	0.77	0.04
Tawas	Yellow perch	0.27	0.27	7.64	7.64	0.03
GLWQA objectives (for whole fish)		0.05	100	100	10	
Pre-Jan. 1978 USFDA Action Level (edible portion)		0.05				
New USFDA Action Level		1.0				

ND = not detectable
---- = no sample analysis for this parameter

Table 16. Mean concentrations of selected organic contaminants in Lake Huron fish, 1974 and 1975. Entries are expressed as mg/kg wet weight basis for edible fillets.

Location	Fish Species	Total DDT	PCB	Dieldrin
		1974		
Hammond Bay	Brown trout	0.57	1.13	0.02
	Yellow perch	ND	ND	ND
	Rainbow trout	0.32	0.94	0.03
	Walleye	0.03	ND	ND
	Whitefish	0.26	ND	0.05
Alpena	Brown trout	0.50	1.10	0.04
	Chinook salmon	0.97	2.30	0.05
	Yellow perch	0.03	ND	TR
	Whitefish	0.35	0.34	0.05
Tawas	Whitefish	0.12	0.22	0.03
Harbor Beach	Yellow perch	0.13	0.03	ND
Lexington	Yellow perch	0.05	0.13	ND
		1975		
Hammond Bay	Lake trout	0.81	1.61	0.05
Alpena	Yellow perch	0.04	0.13	ND
Tawas	Yellow perch	0.07	0.23	ND
GLWQA objectives (whole fish)		1.0	0.1	0.3*
USFDA action level (edible portions)		5.0	5.0	0.3

ND = not detectable
TR = trace
* = aldrin plus dieldrin

PCB concentrations were generally low in 1974 and 1975 in the Lake Huron fish, with brown trout and chinook salmon having the highest levels. The mean for six chinook salmon from Alpena was 2.30 mg/kg, while brown trout from Hammond Bay and Alpena had mean values of 1.13 and 1.09 mg/kg, respectively. The U.S. FDA action level for PCB was not exceeded in any individual fish, and yellow perch, walleye, and whitefish contained less than 1/10 of the tolerance limit. However, all fish analyzed for PCB with the exception of yellow perch from Harbor Beach in 1974, exceeded the GLWQA objective of 0.1 mg/kg for PCB.

Concentrations of DDT, PCB and mercury were generally higher in larger fish as demonstrated by a linear regression analysis performed on whitefish and chinook in 1974. Mercury was also correlated with fish length in yellow perch. In 1975, a significant linear relationship of DDT and PCB but not mercury or dieldrin with length was found in lake trout.

No significant location mean differences were found for PCB or DDT in whitefish at Detour, Tawas or Lexington or in yellow perch from Detour, Alpena, Tawas, Lexington or Harbor Beach.

An analysis of the trends of these fish contaminants based on the GLECS data was completed for lake trout, whitefish and walleye. Lake trout data were available from 1975 through 1978. In addition, data were available for whitefish from 1974 and 1975 and for walleye from 1974 and 1978. In addition to year to year comparisons, location differences were tested, but these differences were inconclusive.

Lake trout dieldrin concentrations were significantly higher in 1976 than 1975 and 1978. All years were significantly higher than 1977 (Table 17). Only one lake trout was above the U.S. FDA action level of 1.0 mg/kg for dieldrin. Concentrations of dieldrin in whitefish were available only for 1974 and 1975 and no significant differences found. Walleye were only analyzed for dieldrin in 1978. No walleye or whitefish exceeded the U.S. FDA action level for dieldrin. The data suggest a decline in dieldrin after 1976 in lake trout based on data from 1975 through 1978. No decline or increase for whitefish based on 1974 and 1975 concentrations was apparent.

The lake trout had significantly higher concentrations of DDT in 1976 than 1975 and 1977. The 1978 DDT concentrations were significantly lower than all other years (Table 18). There was no significant increase or decrease in DDT concentrations in whitefish in 1974 and 1975. The 1978 walleye had significantly higher DDT concentrations than 1974. The 1978 concentrations increased 10 fold over the 1974 concentrations. The data suggest a decline in DDT concentrations in lake trout after 1976 based on data from 1975 through 1978. A small increase in DDT concentrations occurred in walleye based on data for only 1974 and 1978. Without data for the intervening years, trends are difficult to predict. Only one lake trout exceeded the U.S. FDA action level of 5.0 mg/kg DDT.

The most recent data show that PCB did not significantly decline or increase in Lake Huron lake trout from 1974 to 1978 but increased in whitefish from 1974 to 1975 (Table 19). Walleye tested only for PCB in 1978 had mean and maximum

Table 17 Trends in dieldrin in Lake Huron fish 1974-1978

Year and significance α = 0.05	Number and percent of samples exceeding U.S. FDA action level of 0.3 mg/kg #/total	%	Raw data (mg/kg wet weight) Mean	Standard deviation	Minimum value	Maximum value
Lake trout-1976>1975,1978>1977[1]						
1975	0/19	-	0.053	0.021	0.020	0.080
1976	0/23	-	0.139	0.049	0.050	0.220
1977	0/61	-	0.056	0.057	0.005	0.240
1978	1/6	16.6	0.045	0.024	0.010	0.800
Whitefish-no significant difference						
1974	0/36	-	0.043	0.031	0.005	0.140
1975	0/17	-	0.054	0.023	0.010	0.100

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[1] Greater than indicators (>) are significantly different. Underlined values are not significantly different from each other.

Table 18

Trends in DDT in Lake Huron fish 1974-1978

Year and significance $\alpha = 0.05$	Number and percent of samples exceeding U.S. FDA action level of 5.0 mg/kg #/total	%	Raw data (mg/kg wet weight) Mean	Standard deviation	Minimum value	Maximum value
Lake trout - 1976>1975, 1977>1978 [1]						
1975	0/19	-	0.81	0.45	0.16	0.73
1976	0/23	-	1.33	0.81	0.52	3.80
1977	1/61	1.6	1.05	1.19	0.06	7.64
1978	0/6	-	0.21	0.05	0.14	0.27
Whitefish - 1975, 1974						
1974	0/36	-	0.25	0.22	0.03	1.10
1975	0/17	-	0.21	0.06	0.11	0.32
Walleye - 1978>1974						
1974	0/12	-	0.03	0.03	0.01	0.09
1978	0/6	-	0.33	0.24	0.10	0.77

[1] Greater than indicators (>) are significantly different. Underlined values are not significantly different from each other.

Table 19 Trends in PCB in Lake Huron fish 1974-1978

Year and significance $\alpha = 0.05$	Number and percent of samples exceeding U.S. FDA action level of 5.0 mg/kg		Raw data (mg/kg wet weight)			
	#/total	%	Mean	Standard deviation	Minimum value	Maximum value
Lake trout - no significant difference[1]						
1975	1/19	5.3	1.61	1.21	0.36	5.70
1976	0/23	-	1.79	0.92	0.66	4.88
1977	2/61	3.3	2.16	1.26	0.005	7.81
1978	0/6	-	0.81	0.31	0.19	1.02
Whitefish - 1975>1974						
1974	0/36	-	0.19	0.19	0.005	0.75
1975	0/17	-	0.30	0.13	0.14	0.66
Walleye - 1978*						
1978	0/6	-	0.43	0.17	0.23	0.70

*No analysis for PCB in walleye in 1974

[1] Greater than indicators (>) are significantly different. Underlined values are not significantly different from each other.

Table 20 Trends in mercury in Lake Huron fish 1974-1978

Year and significance α = 0.05	Number and percent of samples exceeding U.S. FDA action level of 1.0 mg/kg		Raw data (mg/kg wet weight)			
	#/total	%	Mean	Standard deviation	Minimum value	Maximum value
Lake trout - 1976 1977 1978>1975[1]						
1975	0/19	-	0.146	0.060	0.100	0.370
1976	0/23	-	0.247	0.087	0.080	0.530
1977	0/61	-	0.235	0.058	0.005	0.390
1978	0/6	-	0.205	0.045	0.140	0.270
Whitefish - no significant difference						
1974	0/36	-	0.029	0.024	0.005	0.100
1975	0/17	-	0.034	0.029	0.005	0.070
Walleye - 1978>1974						
1974	0/12	-	0.167	0.049	0.100	0.200
1978	0/6	-	0.692	0.202	0.450	0.950

[1] Greater than indicators (>) are significantly different. Underlined values are not significantly different from each other.

PCB concentrations similar to those for whitefish in 1975. Only one lake trout exceeded the U.S. FDA action level of 5.0 mg/kg PCB in 5.3 and 3.3% of the lake trout in 1975 and 1977, respectively.

The data for mercury indicate that concentrations may have peaked in lake trout by 1976 or 1977 based on data from 1975 through 1978 (Table 20). Mercury concentrations did not change in whitefish from 1974 to 1975. Mercury concentrations were significantly greater in Lake Huron walleye in 1978 than in 1974 and appear to be approaching the U.S. FDA action level of 1.0 mg/kg. However, without data for the intervening years, it is difficult to predict trends.

Summary

Lake Huron is composed of water originating in Lake Superior and Lake Michigan but its water quality is substantially affected by inputs from within the basin. Temperature and dissolved oxygen profiles in Lake Huron varied little with depth. The absence of thermal stratification and orthograde dissolved oxygen depth profiles indicate a thorough mixing of the nearshore waters. Total dissolved solids in Lake Huron averaged twice the levels of Lake Superior with corresponding increases in chlorides and sulfates. Based on background locations, there was a general north to south increase in total dissolved solids, chlorides, sulfates, phosphorus and chlorophyll a levels with corresponding decreases in silica levels.

Areas of lower water quality were found at Cheboygan, Alpena, Saginaw Bay and Harbor Beach. Cheboygan had elevated suspended solids and conservative ions while Alpena and Saginaw Bay were the major sources of phosphorus to Lake Huron. Heavy metals were generally low with some slightly elevated levels detected in 1974, but not in 1975. DDT, DDE and PCBs were generally below detection levels in the Water. PCBs were found at 0.02 and 0.08 μg/l at Alpena and Harrisville, respectively. Wastewater surveys of industrial effluents in the vicinity of these locations did not detect the source of these PCBs Although scattered individual stations were above detection limits, no location exceeded water quality criteria.

Sediment quality in the lake was good at all locations except Cheboygan, Alpena, and especially Harbor Beach, which exceeded U. S. EPA dredge spoil criteria for several metals and organic contaminants. Sediment quality was significantly worse in several of the river mouths, especially Saginaw River, reflecting degraded water quality inputs from rivers.

Bacterial densities were generally low, except at Alpena where total coliform counts were consistently elevated. Other areas, near municipal and industrial wastewater discharges, occasionally exceeded criteria but most nearshore Lake Huron waters had low or nondetectable bacterial densities.

Phytoplankton populations were dominated by diatoms although localized blooms of blue-greens and Cryptophyta were found in the southern portions of the lake, the very nearshore waters, and at Alpena. Zooplankton densities increased from north to south with noticable increases at impacted locations. These locations also had a reduced proportion of calanoids, indicating enriched conditions.

Analysis of benthic macroinvertebrate data indicated a gradual change from oligotrophic conditions at the northern most location (Detour) to a mesotrophic condition at the southern most location (Lexington). Species abundance was affected by depth, bottom type and ambient water quality. Oligotrophic indicator species characterized all background locations. The abundance of Pontoporeia affinis at Presque Isle was assumed to be due to the greater depth at which samples were collected. All impacted locations had diverse, abundant, pollution-tolerant communities, reflecting nutrient inputs from local sources.

Heavy metals in fish were low in all areas for all species and no values exceeded USFDA tolerance limits. Organic contaminants in fish were below detectability, except for PCB and DDT which, when found, were present in relatively low concentrations compared to Lake Superior. The highest concentrations of PCB's were found in chinook salmon and brown trout from Alpena, but no source was found in wastewater surveys of industrial effluents in the vicinity. Nearly all species collected exceeded the GLWQA objective for PCB.

The GLECS reports were available for limited trend analyses. In Lake Huron adequate data were available for analysis of lake trout (1975-1978), whitefish (1974 and 1975) and walleye (1974 and 1978).

In Lake Huron lake trout, dieldrin, DDT and mercury concentrations appear to have peaked in 1976 followed by an apparent decline using the most recent (1975-1978) data. Concentrations of PCB however, did not change significantly from 1975 to 1978.

For whitefish, no significant changes in the concentrations of dieldrin, DDT and mercury in Lake Huron were detected. A significant increase in PCB concentrations in whitefish from 1974 to 1975 did occur.

In Lake Huron walleye, a significant increase in DDT and mercury concentrations in 1978 over 1974 was observed. However, without the intervening years data trends are difficult to predict. The maximum mercury concentration in walleye collected in the northern portion of Lake Huron nearly exceeded the action level. Dieldrin and PCB were not tested for in 1974 in walleye.

LITERATURE CITED

Adams, C. E., Jr. 1970. Summer circulation in Western Lake Superior. Proc. 13th Conf. Great Lakes Res. p. 862-879.

____________, and R. D. Kregear. 1969. Sedimentary and faunal environments in eastern Lake Superior. Proc. 12th Conf. Great Lakes Res. p. 1-20.

American Public Health Association. 1971. Standard Methods for the examination of water and wastewater. Thirteenth edition, New York. 874 p.

American Society of Testing and Materials. 1975. Annual Book of Standards, Part 31, Water. 1975. Philadelphia. 673 p.

Anonymous. 1974. Great Lakes environmental contaminants survey. Unpublished Report. Mich. Dept. of Ag. 41 p.

_________. 1975. Great Lakes environmental contaminants survey. Unpublished Report. Mich. Dept. of Ag. 43 p.

_________. 1976. Great Lakes environmental contaminants survey. Unpublished Report. Mich. Dept. of Ag. 23 p.

_________. 1977. Great Lakes environmental contaminants survey. Unpublished Report. Mich. Dept. of Ag. 15 p.

_________. 1978. Great Lakes environmental contaminants survey. Unpublished Report. Mich. Dept. of Ag.

Aquatic Research Group. 1975. Analysis Report: Keweenaw waterway maintenance dredging. St. Paul Dist., U.S. Army Corps of Eng.

Ayers, J. C. 1962. Great Lakes waters, their circulation and physical and chemical characteristics. In: Great Lakes Basin, Pub. 71 Amer. Assoc. Advancem. Sci. p. 71-89.

Barth, E. F. 1975. Average pH Calculations. Jour. Water Poll. Cont. Fed. 47(8): 2191-2192.

Beal, A. R. 1974. A study of selenium levels in freshwater fishes of Canada's central region. Tech. Rpt. Series No. CEN/T-74-6. Dept. of the Env. Fish. and Marine Serv.

Bedford, J. W. 1974. The use of polyurethane foam plugs for extraction of polychlorinated biphenyls (PCBs) from natural waters. Bull. Env. Cont. and Tox. 12(5): 622-625.

Beeton, A. M. 1965. Eutrophication of the St. Lawrence Great Lakes. Limnol. Oceanogr. 10:240-254.

_______________ and D. C. Chandler. 1963. St. Lawrence Great Lakes. In: D. G. Frey (ed.), *Limnology in North America*. Univ. of Wis. Press, Madison. p. 535-558.

Brinkhurst, R. O. 1964. Studies on the North American aquatic oligochaeta. I. Naididae and Opistocystidae. Proc. Adad. Nat. Sci. Phila. 116(5): 195-230.

__________________ 1965. Studies on the North American aquatic oligochaeta. II. Tubificidae. Proc. Acad. Nat. Sci. Phila. 117(4): 117-172.

__________________ 1969. The distribution of aquatic oligochaeta in Saginaw Bay, Lake Huron. Limnol. Oceanogr. 12:137-143.

__________________, and D. G. Cook. 1966. Studies on the North American aquatic oligochaeta. III. Lumbriculidae and additional notes and words of other families. Proc. Acad. Nat. Sci. Phila. 118(1): 1-33.

__________________, A. L. Hamilton and H. B. Herington. 1968. Components of the bottom fauna of the St. Lawrence Great Lakes. Univ. Toronto Great Lakes. Inst. No. PR 33. 50 p.

__________________, and B. G. M. Jamieson. 1971. *Aquatic oligochaeta of the world*. Univ. of Toronto Press, Toronto. 680 p.

Canadian Department of National Health and Welfare. 1972. Poisonous substances in food. Food and Drug Direct., Food and Drugs Act, Section 4(a).

Chandler, D. C. 1964. The St. Lawrence Great Lakes. Verh. Internat. Verein. Limnol. 15:59-75.

Conway, J. B. 1977. Seasonal and depth distribution of *Limnocalanus macrurus* at a site on Western Lake Superior. J. Great Lakes Res. 3(1-2):15-19.

Cook, D. G. and M. G. Johnson, 1974. Benthic macroinvertebrates of the St. Lawrence Great Lakes. J. Fish Res. Board Can. 31:763-782.

Davis, C. C. 1966. Plankton studies in the largest great lakes of the world. Univ. Mich. Great Lakes Res. Div. Pub 14.

Dobson, H. F. H., M. Gilbertson, and P. G. Sly. 1974. A summary and comparison of nutrients and related water quality in lakes Erie, Ontario, Huron, and Superior. J. Fish. Res. Board Can. 31:731-738.

Dole, R. B. 1909. The quality of surface waters in the United States. Part 1. Analysis of waters east of the one hundredth meridian. U.S. Geol. Surv. Water-Supply Pap. 236:123 p.

Douglas, G. S. ed. 1967. Radio-assay procedures for environmental samples. Public Health Service. U.S. Gov. Printing Office. Wash. D.C. Doc. 999-RH-27. 558 p.

Federal Water Pollution Control Administration. 1969. An appraisal of water pollution in the Lake Superior Basin. U.S. Dept. of Int. Washington, D.C.

Food and Drug Administration. 1974. Poisonous or deleterious substances in peanuts, evaporated milk, fish and shellfish. Proposed rules. Fed. Reg. Dec. 6, 1974, Wash. D.C.

German, M. J. W. 1967. Biological survey of the Kaministikwia River and Thunder Bay, 1965-1966. Ont. Water Resour. Comm. p. 1-24.

______________. 1968. Biological survey of Nipigon Bay, 1966-1967. Ont. Water Resour. Comm. p. 1-22.

________________ and D. M. Pugh. 1969. Biological evaluation of the pollution status of Jackfish Bay, Lake Superior. Ont. Water Resour. Comm. p. 1-17.

Henson, E. B. 1966. A review of Great Lakes benthos research. Univ. Mich. Great Lakes Res. Div. 14:37-54.

____________, E. C. Keller, A. J. McErlean, W. P. Alley and P. E. Etter. 1973. The ecological effect of taconite tailings disposal on the benthic populations of western Lake Superior. Studies regarding the effect of the Reserve Mining Company discharge on Lake Superior, Supplement May 18, 1975 U.S. EPA Office of Enforcement and General Counsel. Washington, D.C.

Hiltunen, J. K. 1969. Invertebrate macrobenthos of western Lake Superior Mich. Academ. 1(3-4): 123-133.

Holland, R. E. 1965. The distribution and abundance of planktonic diatoms in Lake Superior. Proc. 8th Conf. Great Lakes Res. Univ. Mich. Great Lakes Res. Div. Pub. 13.

Hundley, H. K. and J. C. Underwood. 1970. Arsenic analysis. J. AOAC 53(6)1176.

International Joint Commission. 1974. Appendix A. Water Quality Objective Subcommittee Report, Great Lakes Water Qual. Bd. IJC.

________________________. 1977. New and revised Great Lakes water quality objectives. IJC.

————————. 1977. The waters of Lake Huron and Lake Superior Volume II. Part A. Lake Huron, Georgian Bay and the North Channel. Upper Lakes Reference Group. IJC.

————————, 1977. The waters of Lake Huron and Lake Superior Volume III. Part B. Lake Superior, Upper Lakes Reference Group. IJC.

————————. 1978. Great Lakes Water Quality Agreement of 1978. Agreement, with annexes and terms of reference between the United States of America and Canada signed at Ottawa, November 22, 1978. 30 p.

Lowe, R. L. 1974. Environmental requirements and pollution tolerances of freshwater diatoms. EPA-670/4-74-005. 340 p.

Lucas, H. F., Jr., D. N. Edgington and P. J. Colby. 1970. Concentrations of trace elements in Great Lakes fishes. J. Fish. Res. Bd. Can. 27(4):677-684.

McKee, J. E. and H. W. Wolf (eds.). 1963. Water quality criteria. 2nd ed. Res. Agency of Calif. State Water Qual. Cont. Bd. Sacramento. Pub. 3A 548 p.

Meranger, J. C. and E. Somers. 1968. Heavy metals analysis. Bull. Env. Cont. and Tox. 3(6):360.

Michigan Water Resources Commission. 1957. Biological survey of South Bay, Lake Superior at Munising, Michigan. Mich. Dept. Nat. Res.

————————. 1965a. Biological surveys of Thunder Bay and Thunder Bay River, Alpena, Michigan, 1957 and 1965. Mich. Dept. Nat. Res.

————————. 1965b. Biological survey of the harbor vicinity, Lake Huron, Harbor Beach, June 6, 1958 and August 5, 1965. Mich. Dept. of Nat. Res.

————————. 1968. A biological survey of South Bay, Lake Superior and observations on the Anna River, Munising, August 6, 1968. Mich. Dept. of Nat. Res. Unpublished report.

————————, 1969a. A biological survey of the Carp River and the vicinity of the Marquette wastewater treatment plant, 1968. Mich. Dept. of Nat. Res. Unpublished report.

————————. 1969b. Report on water pollution control in the Michigan portion of the Lake Superior Basin and its tributaries. Mich. Dept. of Nat. Res.

————————. 1973. A biological survey of the Carp River in the vicinity of the Marquette Wastewater Treatment Plant, Marquette County, October 2, 1972. Mich. Dept. Nat. Res.

______________________. 1975. Water quality station inventory. p. 18. Mich. Dept. Nat. Res.

Michigan Water Resources Commission, 1977. General rules. Part 4. Water quality standards.

Mozley, S. C. 1975. Species composition of zoobenthos in western Lake Huron. Proc. 18th Conf. Gr. Lakes Res.

Murty, T. S. and D. B. Rao. 1970. Wind-generated circulations in Lakes Erie, Huron, Michigan and Superior. Proc. 13th Conf. Great Lakes Res. p. 927-941.

Musty, P. R. and G. Nickless. 1974. The extraction and recovery of chlorinated insecticides and polychlorinated biphenyls from water using porous polyurethane foam. J. Chrom. 100:83-93.

National Academy of Sciences. 1972. Water quality criteria. Gov't. Printing Office, Washington, D.C.

Nauwerck, A. 1972. Notes on the rotifers of Lake Ontario. Can. Cent. Inland Waters. Great Lakes Biolimnology Lab. Unpub. Report.

Patalas, K. 1969. Composition and horizontal distribution of crustacean zooplankton in Lake Ontario. J. Fish. Res. Bd. Can. 26(8):2135-2164.

__________. 1972. Crustacean plankton and the eutrophication of the St. Lawrence Great Lakes. J. Fish. Res. Bd. Can. 29(10):1451-1462.

Poldoski, J. E. and G. E. Glass. 1974. Methodological considerations in Western Lake Superior water-sediment exchange studies of some trace elements. Presented at 7th Materials Research Symposium. Accuracy in trace analysis. October 7-11, 1974. Nat. Bur. Std. Gaithersburg, Md.

______________________. 1975. Considerations of trace element chemistry for streams in the Minnesota-Ontario border area. Proc. of the inter. Conf. on Heavy Metals in the Env. Oct. 27-31, 1975. Toronto, Ontario, Canada.

Rao, S. S. and J. Henderson. 1974. Summary report of microbiological baseline data on Lake Superior. Scientific Report Series No. 45, Inland Waters Directorate Can. Cent. for Inland Waters, Burlington.

Reinert, R. E. 1970. Summary of available information from the Bureau of Commercial Fisheries, Ann Arbor. Bio. Lab. on Pesticide Levels in Great Lakes Fish.

Saether, O. A. 1975a. Nearctic and palaearctic Heterotrissocladius (Diptera: Chironomidae). Bull. Fish. Res. Bd. Can. 193:67.

_____________. 1975b. Two new species of Protanypus kieffer, with keys to nearctic and palaearctic species of the genus (Diptera:Chironomidae). J. Fish. Res. Bd. Can. 32:367-388.

Schelske, C. L., L. E. Feldt, M. A. Santiago and E. F. Stoermer. 1972. Nutrient enrichment and its effect on phytoplankton production and species composition in Lake Superior. Proc. 15th Conf. Great Lakes Res.

_______________, and J. C. Roth. 1973. Limnological survey of Lakes Michigan, Superior, Huron and Erie. Great Lakes Res. Div., Univ. Mich. Pub. 17.

_______________, L. E. Feldt, M. S. Simmons and E. F. Stoermer. 1974. Storm induced relationships among chemical conditions and phytoplankton in Saginaw Bay and Western Lake Huron. Proc. 17th Conf. Great Lakes Res. p. 78-91.

Schneider, J. C., H. F. Hooper and A. M. Beeton. 1969. The distribution and abundance of benthic fauna in Saginaw Bay, Lake Huron. Proc. 12th Conf. Great Lakes Res.

Schuytema, G. S. and R. E. Powers. 1966. The distribution of benthic fauna in Lake Huron. Great Lakes Res. Div. Univ. Mich., Pub. 15.

Selgeby, J. H. 1975. Life histories and abundance of crustacean zooplankton in the outlet of Lake Superior, 1971-1972. J. Fish. Res. Bd. Can. 32(4)461-470.

Shrivastava, H. 1974. Macrobenthos of Lake Huron. Fish. Res. Bd. Can. Tech. Rpt. 449.

Smith, V. E., K. W. Lee, J. C. Filkins, K. W. Hartwell, K. R. Rygwelski and J. M. Townsend. 1977. Survey of chemical factors in Saginaw Bay (Lake Huron). EPA-600/3-77-125.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Company, San Francisco, Calif. 776 p.

Swain, W. R., R. M. Wilson, R. P. Neri and G. S. Porter. 1975. "Persistent organic and heavy metal residues in the nearshore fishery of Western Lake Superior", A final report to the Environmental Protection Agency. Univ. of Minnesota, Lake Superior Basin Study Center, Duluth. December 31, 1975. ULRG D-33.

Teter, H. E. 1960. The bottom fauna of Lake Huron. Trans. Amer. Fish. Soc. 89:193-197.

Thommes, M., H. F. Lucas Jr. and D. N. Eddington. 1972. Mercury concentrations in fish taken from offshore areas of the Great Lakes. Proc. 15th Conf. Great Lakes Res.

U. S. Department of Health, Education and Welfare. 1974. Food and Drug Administration. In: Pesticide Analytical Manual, Vol. I.

U. S. Environmental Protection Agency. 1973. Method for polychlorinated biphenyls (PCBs) in industrial effluents. National pollutants discharge elimination system, Appendix A. Fed. Reg. 38(75) part II.

____________________________________. 1974. The relationships of phosphorus and nitrogen to the tropic state of northeast and north-central lakes and reservoirs. Working paper no. 23. Pacific N.W. Env. Res. Lab. Corvallis, Ore.

____________________________________. 1974. Manual of Methods for chemical analysis of water and wastes. Wash. D.C. 298 p.

____________________________________. 1976. Quality Criteria for Water. Wash. D.C. 256 p.

____________________________________. 1977. Guidelines for the pollutional classification of Great Lakes Harbor sediments. U. S. EPA Region V. Chicago, Ill.

Uthe, J. F. and E. C. Bligh. 1971. Preliminary survey of heavy metal contamination of Canadian freshwater fish. J. Fish. Res. Bd. Can. 28(5):786-788.

Vollenweider, R. A., M. Munawar and P. Stadelman. 1974. A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. J. Fish. Res. Bd. Can. 31(5):739-762.

Water Quality Objectives Subcommittee. 1976. Great Lakes Water Quality. 1975. Appendix A. Water Quality Objectives Subcommittee report. IJC.

Watson, N. H. F. 1974. Zooplankton of the St. Lawrence Great Lakes - species composition, distribution and abundance. J. Fish. Res. Bd. Can. 31(5):783-794.

Weiler, R. R. and V. K. Chawla. 1969. Dissolved mineral quality of Great Lakes waters. Proc. 12th Conf. Great Lakes Res. p. 801-818.

Winter, D. R. 1968. Report on the water quality survey in the Wisconsin waters of Lake Superior made during July, 1968. Wis. Dept. Nat. Res. Div. of Envir. Prot. Madison, Wisc.

Yeske, L. A., T. Green III, F. L. Scarpace and R. E. Terrell. 1972. Current measurements in Lake Superior using aerial photogrammetric techniques: a preliminary report. Proc. 15th Conf. Great Lakes Res. p. 689-698.

SECTION VIII APPENDICES

Table A-1. Lakes Superior and Huron nearshore sampling locations, STORET numbers, latitudes and longitudes, 1974.

Location Number	Location	Station Number	STORET Number	Lat. N.	Long. W.
1	Black River*	1	270058	46° 40' 14"	90° 02' 59"
		2	270059	46° 41' 02"	90° 02' 28"
		3	270060	46° 40' 38"	90° 03' 29"
		4	270061	46° 40' 23"	90° 04' 31"
		5	270062	46° 40' 52"	90° 04' 44"
		6	270063	46° 41' 18"	90° 03' 43"
		7	270064	46° 41' 36"	90° 02' 33"
2	Ontonagon	1	660052	46° 52' 52"	89° 19' 54"
		2	660053	46° 53' 09"	89° 19' 30"
		3	660054	46° 52' 57"	89° 19' 54"
		4	660055	46° 52' 55"	89° 20' 11"
		5	660056	46° 53' 43"	89° 21' 23"
		6	660057	46° 53' 51"	89° 20' 23"
		7	660058	46° 54' 00"	89° 18' 53"
		8	660059	46° 51' 15"	89° 19' 22"
		9	660060	46° 51' 53"	89° 19' 50"
		10	660061	46° 52' 14"	89° 20' 18"
		11	660062	46° 52' 38"	89° 20' 53"
		12	660063	46° 53' 49"	89° 20' 45"
3	Upper Portage	1	310073	47° 14' 07"	88° 37' 53"
		2	310074	47° 14' 45"	88° 37' 43"
		3	310075	47° 14' 37"	88° 38' 11"
		4	310076	47° 14' 19"	88° 38' 50"
4	Lower Portage	1	310069	46° 57' 54"	88° 25' 50"
		2	310070	46° 57' 05"	88° 26' 13"
		3	310071	46° 57' 23"	88° 25' 47"
		4	310072	46° 57' 48"	88° 25' 21"
5	Eagle Harbor*	1	420023	47° 27' 56"	88° 07' 55"
		2	420024	47° 28' 14"	88° 07' 07"
		3	420025	47° 28' 17"	88° 07' 52"
		4	420026	47° 28' 05"	88° 05' 05"
6	Isle Royale*	1	420019	48° 09' 27"	88° 36' 01"
		2	420020	48° 09' 46"	88° 34' 36"
		3	420021	48° 09' 43"	88° 35' 30"
		4	420022	48° 09' 35"	88° 36' 20"
7	Big Bay*	1	520114	46° 49' 38"	87° 42' 32"
		2	520115	46° 49' 54"	87° 42' 08"
		3	520116	46° 50' 05"	87° 42' 22"
		4	520117	46° 50' 21"	87° 43' 44"
		5	520118	46° 51' 37"	87° 43' 20"
		6	520119	46° 51' 29"	87° 42' 12"
		7	520120	46° 51' 37"	87° 41' 29"
8	Presque Isle	1	520109	46° 34' 37"	87° 23' 23"
		2	520110	46° 34' 16"	87° 23' 14"
		3	520111	46° 34' 26"	87° 23' 08"
		4	520112	46° 34' 39"	87° 23' 11"
		5	520113	46° 34' 24"	87° 22' 20"
		6	520128	46° 33' 57"	87° 22' 18"
		7	520129	46° 33' 32"	87° 22' 39"
9	Munising	1	020018	46° 24' 44"	86° 38' 29"
		2	020019	46° 25' 07"	86° 38' 16"
		3	020020	46° 25' 02"	86° 38' 27"
		4	020021	46° 24' 59"	86° 38' 44"
		5	020022	46° 25' 25"	86° 39' 00"
		6	020023	46° 25' 25"	86° 38' 34"
		7	020024	46° 25' 30"	86° 37' 54"
		8	020025	46° 26' 24"	86° 39' 02"
		9	020026	46° 25' 34"	86° 39' 17"
		10	020027	46° 24' 57"	86° 39' 20"
		11	020028	46° 24' 47"	86° 38' 45"
		12	020029	46° 24' 52"	86° 38' 22"
		13	020030	46° 25' 47"	86° 37' 39"
10	Grand Marais*	1	020031	46° 40' 45"	85° 58' 59"
		2	020032	46° 40' 57"	85° 58' 57"
		3	020033	46° 40' 56"	85° 59' 16"
		4	020034	46° 40' 50"	85° 59' 57"
		5	020035	46° 41' 15"	86° 01' 07"
		6	020036	46° 41' 26"	85° 59' 59"
		7	020037	46° 41' 39"	85° 59' 27"
11	Whitefish Point* (spring)	1	170068	46° 46' 29"	84° 57' 13"
		2	170069	46° 46' 20"	84° 56' 47"
		3	170070	46° 46' 39"	84° 56' 59"
		4	170071	46° 46' 41"	84° 57' 22"
		5	170072	46° 47' 06"	84° 57' 18"
		6	170073	46° 47' 00"	84° 56' 36"
		7	170074	46° 46' 33"	84° 55' 44"
	(fall)	1	170061	46° 45' 21"	84° 57' 43"
		2	170062	46° 44' 41"	84° 58' 04"
		3	170063	46° 45' 07"	84° 57' 26"
		4	170064	46° 45' 52"	84° 57' 03"
		5	170065	46° 45' 13"	84° 56' 49"
		6	170066	46° 44' 50"	84° 56' 50"
		7	170067	46° 44' 38"	84° 57' 04"
21	Marquette Carp River	1	520121	46° 31' 08"	87° 22' 57"
		2	520122	46° 30' 55"	87° 22' 29"
		3	520123	46° 31' 21"	87° 22' 40"
		4	520124	46° 31' 14"	87° 22' 56"
		5	520125	46° 31' 22"	87° 23' 07"
		6	520126	46° 31' 39"	87° 22' 51"
		7	520127	46° 31' 08"	87° 22' 16"

* Background locations

Table A-1. (continued) Lakes Superior and Huron nearshore sampling locations, STORET numbers, latitudes and longitudes, 1974.

Location Number	Location	Station Number	STORET Number	Lat. N.	Long. W.
12	Detour*	1	170054	45° 57' 05"	83° 55' 05"
		2	170055	45° 57' 19"	83° 55' 48"
		3	170056	45° 57' 06"	83° 55' 24"
		4	170057	45° 56' 51"	83° 55' 14"
		5	170058	45° 56' 28"	83° 55' 01"
		6	170059	45° 56' 38"	83° 56' 16"
		7	170060	45° 57' 09"	83° 57' 03"
13	Cheboygan	1	160054	45° 39' 24"	84° 27' 46"
		2	160055	45° 39' 53"	84° 26' 45"
		3	160056	45° 39' 55"	84° 27' 17"
		4	160057	45° 40' 05"	84° 27' 50"
		5	160058	45° 40' 43"	84° 28' 02"
		6	160059	45° 40' 48"	84° 26' 41"
		7	160060	45° 40' 37"	84° 25' 26"
14	Presque Isle*	1	710036	45° 21' 34"	83° 32' 13"
		2	710037	45° 21' 13"	83° 31' 25"
		3	710038	45° 21' 47"	83° 32' 20"
		4	710039	45° 21' 38"	83° 33' 56"
		5	710040	45° 22' 22"	83° 34' 06"
		6	710041	45° 22' 15"	83° 32' 11"
		7	710042	45° 21' 49"	83° 29' 51"
15	Alpena	1	040069	45° 03' 34"	83° 25' 22"
		2	040070	45° 03' 23"	83° 25' 26"
		3	040071	45° 03' 28"	83° 25' 00"
		4	040072	45° 03' 39"	83° 24' 55"
		5	040073	45° 03' 40"	83° 24' 20"
		6	040074	45° 03' 14"	83° 24' 32"
		7	040075	45° 03' 06"	83° 25' 10"
		8	040076	45° 03' 06"	83° 24' 56"
		9	040079	45° 02' 58"	83° 24' 03"
		10	040080	45° 03' 09"	83° 24' 01"
16	Harrisville*	1	010022	44° 42' 41"	83° 15' 57"
		2	010023	44° 41' 44"	83° 14' 50"
		3	010024	44° 42' 34"	83° 14' 42"
		4	010025	44° 43' 36"	83° 14' 50"
		5	010026	44° 44' 24"	83° 13' 35"
		6	010027	44° 43' 05"	83° 13' 18"
		7	010028	44° 40' 32"	83° 14' 01"
17	Tawas City*	1	350067	44° 15' 25"	83° 31' 29"
		2	350068	44° 14' 52"	83° 31' 34"
		3	350069	44° 15' 07"	83° 31' 14"
		4	350070	44° 15' 54"	83° 30' 09"
		5	350071	44° 15' 31"	83° 29' 33"
		6	350072	44° 14' 46"	83° 29' 52"
		7	350073	44° 13' 36"	83° 30' 39"
18	Saginaw Bay	1	090180	43° 41' 05"	83° 46' 45"
		2	790091	43° 54' 35"	83° 31' 40"
		3-spring	320127	44° 03' 45"	83° 25' 50"
		3-fall	320129	44° 01' 25"	83° 20' 25"
		4	320128	44° 04' 10"	83° 04' 50"
19	Harbor Beach	1	320107	43° 50' 48"	82° 38' 34"
		2	320108	43° 50' 38"	82° 38' 24"
		3	320109	43° 50' 47"	82° 38' 21"
		4	320120	43° 51' 08"	82° 38' 32"
		5	320121	43° 51' 15"	82° 37' 58"
		6	320122	43° 50' 16"	82° 37' 37"
		7	320123	43° 50' 42"	82° 37' 59"
		8	320124	43° 50' 40"	82° 37' 33"
		9	320125	43° 50' 29"	82° 38' 19"
		10	320126	43° 50' 56"	82° 38' 05"
20	Lexington*	1	760095	43° 16' 20"	82° 31' 23"
		2	760096	43° 16' 06"	82° 31' 04"
		3	760097	43° 16' 26"	82° 31' 06"
		4	760098	43° 16' 42"	82° 31' 09"
		5	760099	43° 17' 13"	82° 29' 54"
		6	760100	43° 16' 37"	82° 29' 31"
		7	760101	43° 16' 11"	82° 29' 25"

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* Background Locations

Table A-2. Lakes Superior and Huron nearshore sampling locations, STORET numbers, latitudes and longitudes, 1975.

Location Number	Location	Station Number	STORET Number	Lat. N.	Long. W.
1	Black River *	R †	270067	46° 40' 00"	90° 02' 52"
		4	270063	46° 41' 40"	90° 04' 08"
2	Ontonagon	R †	660066	46° 52' 37"	89° 19' 40"
		1	660052	46° 52' 53"	89° 19' 54"
		2	660068	46° 53' 09"	89° 20' 08"
		3	660057	46° 54' 05"	89° 21' 15"
		4	660070	46° 54' 45"	89° 21' 45"
3	Upper Portage	R †	310091	47° 13' 25"	88° 37' 25"
		4	310092	47° 16' 45"	88° 39' 00"
4	Lower Portage	R †	310089	46° 59' 00"	88° 26' 07"
		4	310090	46° 57' 23"	88° 24' 15"
5	Eagle Harbor *	1	420031	47° 27' 50"	88° 08' 37"
		2	420032	47° 27' 55"	88° 08' 35"
		3	420033	47° 28' 00"	88° 08' 33"
		4	420025	47° 28' 15"	88° 08' 33"
6	Isle Royale *	1	420035	48° 08' 15"	88° 28' 53"
		2	420036	47° 56' 20"	88° 46' 30"
		3	420037	47° 48' 30"	89° 10' 00"
		4	420038	47° 55' 10"	89° 12' 37"
		5	420039	48° 03' 20"	88° 49' 53"
		6	420021	48° 09' 43"	88° 35' 30"
7	Big Bay *	1	520174	46° 50' 00"	87° 59' 20"
		4	520119	46° 51' 15"	87° 42' 24"
8	Presque Isle	R †	520169	46° 34' 38"	87° 23' 33"
		1	520109	46° 34' 37"	87° 23' 20"
		2	520171	46° 34' 29"	87° 22' 50"
		3	520113	46° 34' 14"	87° 22' 27"
		4	520173	46° 33' 49"	87° 21' 22"
9	Munising	R †	020047	46° 24' 21"	86° 38' 30"
		1	020018	46° 24' 46"	86° 38' 31"
		2	020020	46° 25' 03"	86° 38' 40"
		3	020023	46° 25' 31"	86° 38' 35"
		4	020051	46° 27' 02"	86° 38' 08"
10	Grand Marais *	1	020031	46° 40' 48"	85° 59' 00"
		2	020033	46° 40' 55"	85° 59' 10"
		3	020037	46° 41' 25"	85° 59' 07"
		4	020046	46° 41' 55"	85° 59' 32"
21	Carp River	R †	520160	46° 31' 08"	87° 23' 03"
		1	520121	46° 31' 10"	87° 22' 55"
		2	520162	46° 31' 29"	87° 22' 22"
		3	520163	46° 31' 30"	87° 22' 14"
		4	520164	46° 32' 16"	87° 20' 45"
24	Marquette - Harbor Area	1	520165	46° 32' 30"	87° 22' 55"
		2	520166	46° 32' 14"	87° 22' 57"
		3	520167	46° 31' 53"	87° 22' 33"
		4	520168	46° 31' 30"	87° 22' 14"
25	Tahquamenon River*	R †	170089	46° 33' 30"	85° 01' 53"
		4	170090	46° 35' 00"	84° 56' 39"

*Background locations
†R = River stations

Table A-2 (continued) Lakes Superior and Huron nearshore sampling locations, STORET numbers, latitudes and longitudes, 1975.

Location Number	Location	Station Number	STORET Number	Lat. N.	Long. W.
12	Detour *	1	170054	45° 57' 06"	83° 55' 07"
		2	170057	45° 56' 58"	83° 55' 02"
		3	170058	45° 56' 40"	83° 54' 55"
		4	170088	45° 56' 20"	83° 55' 07"
13	Cheboygan	R †	160066	45° 39' 09"	84° 28' 00"
		1	160054	45° 39' 30"	84° 27' 41"
		2	160056	45° 40' 03"	84° 27' 09"
		3	160069	45° 40' 22"	84° 26' 50"
		4	160070	45° 41' 20"	84° 26' 02"
14	Presque Isle *	1	710036	45° 21' 24"	83° 32' 17"
		2	710047	45° 21' 29"	83° 32' 15"
		3	710038	45° 21' 35"	83° 32' 13"
		4	710041	45° 22' 02"	83° 32' 02"
15	Alpena	R †	040086	45° 03' 44"	83° 25' 40"
		1	040071	45° 03' 18"	83° 25' 00"
		2	040088	45° 03' 02"	83° 24' 30"
		3	040089	45° 02' 50"	83° 24' 03"
		4	040090	45° 00' 31"	83° 21' 15"
		5	040073	45° 03' 47"	83° 24' 24"
		6	040092	45° 03' 24"	83° 24' 17"
16	Harrisville *	1	010022	44° 42' 40"	83° 15' 56"
		2	010032	44° 42' 40"	83° 15' 38"
		3	010033	44° 42' 40"	83° 15' 10"
		4	010024	44° 42' 42"	83° 14' 30"
17	Tawas	R †	350079	44° 15' 32"	83° 31' 48"
		4	350072	44° 14' 49"	83° 29' 26"
18	Saginaw Bay	R †	090185	43° 38' 35"	83° 50' 54"
		1	090186	43° 39' 36"	83° 50' 54"
		2	790102	43° 49' 39"	83° 41' 54"
		3	720157	43° 59' 48"	83° 20' 12"
		4	320158	44° 07' 43"	83° 18' 45"
19	Harbor Beach	1	320109	43° 50' 43"	82° 38' 23"
		2	320123	43° 50' 42"	82° 37' 55"
		3	320155	43° 50' 43"	82° 37' 37"
		4	320156	43° 50' 43"	82° 36' 27"
20	Lexington *	1	760095	43° 16' 12"	82° 31' 10"
		2	760096	43° 16' 14"	82° 30' 51"
		3	760118	43° 16' 18"	82° 30' 26"
		4	760100	43° 16' 27"	82° 29' 39"
22	Calcite *	1	710050	45° 24' 40"	83° 46' 41"
		2	710051	45° 24' 53"	83° 46' 25"
		3	710052	45° 24' 59"	83° 46' 15"
		4	710053	45° 25' 30"	83° 45' 18"

*Background locations
†R = River stations

Table A-3. Descriptive statistics for selected physical and chemical constituents in the nearshore waters of Lakes Superior and Huron, 1974

	Temperature (c)								
	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	18	9.3	1.8	18	14.3	0.6	36	11.8	2.8
Ontonagon	18	10.2	1.1	18	14.8	0.6	36	12.5	2.4
Upper Portage Entry	9	7.8	0.4	9	15.0	0.1	18	11.4	3.6
Lower Portage Entry	9	6.8	1.8	9	14.0	2.2	18	10.4	4.1
Eagle Harbor	9	8.1	1.5	7	15.4	0.9	16	11.3	3.8
Isle Royale	6	3.3	0.3	3	13.7	0.3	9	6.7	5.2
Big Bay	18	6.8	0.7	17	15.7	1.9	35	11.1	4.6
Presque Isle (Marquette)	17	6.6	1.7	14	14.1	1.6	31	10.3	4.0
Carp River (Marquette)	15	9.9	0.3	15	14.9	0.3	30	12.4	2.5
Munising	18	8.1	0.4	18	13.5	3.5	36	10.8	3.6
Grand Marais	18	7.3	0.5	18	17.2	0.1	36	12.5	4.9
Whitefish Point	15	9.3	1.3	15	17.0	0.1	30	13.1	3.9
Lake Huron									
Detour	18	12.0	3.7	18	9.8	3.0	36	10.9	3.5
Cheboygan	18	14.8	0.4	18	14.3	0.4	36	14.5	0.4
Presque Isle	17	12.9	1.7	17	15.2	0.3	34	14.0	1.6
Alpena	18	16.9	1.2	18	17.3	0.3	36	17.1	0.8
Harrisville	18	13.9	1.4	18	18.8	0.3	36	16.3	2.6
Tawas	16	12.4	0.5	18	19.2	0.2	34	16.0	3.4
Saginaw Bay	8	18.8	6.3	8	11.3	0.4	16	15.0	5.8
Harbor Beach	16	15.1	1.1	15	19.8	1.0	31	17.4	2.5
Lexington	18	12.9	0.9	18	19.6	0.1	36	16.3	3.4

	Dissolved Oxygen (mg/1)								
	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	16	10.2	1.0	17	8.9	0.3	33	9.5	1.0
Ontonagon	18	10.2	0.2	18	8.7	0.1	36	9.4	0.8
Upper Portage Entry	9	10.9	0.2	9	8.9	0.1	18	9.9	1.0
Lower Portage Entry	9	10.9	0.3	9	9.4	0.5	18	10.2	0.9
Eagle Harbor	9	13.0	0.2	7	8.5	0.4	16	11.0	2.3
Isle Royale	6	11.5	0.2	3	8.9	0.1	9	10.6	1.3
Big Bay	18	13.2	0.1	17	10.7	0.5	35	12.0	1.3
Presque Isle (Marquette)	17	10.8	0.2	14	10.0	0.5	31	10.8	0.4
Carp River (Marquette)	15	10.2	0.1	15	10.6	0.1	30	10.4	0.2
Munising	18	11.3	0.6	18	10.8	0.7	36	11.0	0.7
Grand Marais	18	12.6	0.2	18	10.1	0.1	36	11.4	1.3
Whitefish Point	14	11.9	0.1	15	9.7	0.2	29	10.7	1.1
Lake Huron									
Detour	18	11.5	1.2	18	11.7	0.8	36	11.6	1.0
Cheboygan	18	10.8	0.5	18	10.4	0.1	36	10.6	0.4
Presque Isle	17	9.6	0.5	17	19.2	0.2	34	9.9	0.5
Alpena	18	9.7	0.3	18	11.0	0.2	36	10.4	0.7
Harrisville	17	11.4	0.4	18	10.5	0.2	35	11.0	0.6
Tawas	17	11.2	0.3	18	10.9	0.1	35	11.0	0.3
Saginaw Bay	3	9.2	1.4	8	11.7	0.5	11	11.0	1.5
Harbor Beach	16	8.6	0.4	15	9.7	0.2	31	9.1	0.6
Lexington	18	9.1	0.3	18	10.0	0.1	36	9.6	0.5

Table A-3 (continued)

pH

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	4	7.7		4	7.7		8	7.7	
Ontonagon	12	7.7		12	7.7		24	7.7	
Upper Portage Entry	6	7.8		6	7.8		12	7.8	
Lower Portage Entry	-	-		6	7.7		-	-	
Eagle Harbor	2	7.6		2	7.7		4	7.7	
Isle Royale	6	7.4		4	7.6		10	7.5	
Big Bay	-	-		4	7.9		-	-	
Presque Isle (Marquette)	-	-		6	[illegible]		-	-	
Carp River (Marquette)	11	7.7		12	7.6		23	7.7	
Munising	9	[illegible]		12	7.6		21	7.6	
Grand Marais	4	7.7		4	7.7		8	7.7	
Whitefish Point	4	8.0		4	[illegible]		8	7.9	
Lake Huron									
Detour	4	7.8		4	7.8		8	7.8	
Cheboygan	12	8.3		12	8.1		24	8.2	
Presque Isle	4	8.1		4	8.0		8	8.0	
Alpena	12	8.1		12	8.2		24	8.2	
Harrisville	4	8.0		4	8.2		8	8.1	
Tawas	12	8.2		12	8.3		24	8.2	
Saginaw Bay	6	[illegible]		6	8.2		12	8.2	
Harbor Beach	12	7.9		12	8.1		24	8.0	
Lexington	4	7.9		4	8.3		8	8.1	

Turbidity (J.T.U.)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	4	2.0	1.2	4	1.0	0.2	8	1.6	1.0
Ontonagon	12	1.8	0.6	12	1.6	1.0	24	1.7	0.8
Upper Portage Entry	6	1.5	0.3	6	1.1	0.7	12	1.3	0.6
Lower Portage Entry	6	1.0	0.6	6	0.6	0.1	12	0.8	0.5
Eagle Harbor	2	2.0	0.0	2	0.5	0.0	4	1.5	0.8
Isle Royale	6	0.8	0.1	4	0.5	0.0	10	0.7	0.2
Big Bay	6	0.7	0.0	4	0.5	0.1	10	0.6	0.1
Presque Isle (Marquette)	12	0.8	0.1	12	0.5	0.1	24	0.7	0.2
Carp River (Marquette)	11	0.8	0.1	12	0.6	0.1	23	0.7	0.1
Munising	11	1.2	0.7	12	1.0	1.9	23	1.1	1.4
Grand Marais	4	0.6	0.0	4	0.6	0.1	8	0.6	0.0
Whitefish Point	4	0.7	0.1	4	0.5	0.1	8	0.6	0.1
Lake Huron									
Detour	4	1.0	0.6	4	1.4	0.4	8	1.2	0.5
Cheboygan	12	1.0	0.2	12	1.3	0.3	24	1.1	0.3
Presque Isle	4	1.0	0.3	4	1.1	0.8	8	1.0	0.6
Alpena	12	2.7	3.1	12	2.3	0.6	24	2.5	2.2
Harrisville	4	0.6	0.1	4	1.0	0.3	8	0.8	0.3
Tawas	12	1.1	0.3	12	0.7	0.1	24	0.9	0.3
Saginaw Bay	6	2.4	1.3	6	6.2	5.4	12	4.7	4.4
Harbor Beach	12	3.2	1.6	12	3.3	3.2	24	3.2	2.5
Lexington	4	1.4	0.3	4	0.8	0.0	8	1.0	0.3

continued

Table A-3 (continued)

Alkalinity (mg/l)

Lake Superior	SPRING n	SPRING X̄	SPRING SD	FALL n	FALL X̄	FALL SD	ANNUAL n	ANNUAL X̄	ANNUAL SD
Black River	4	42	0	4	41	1	8	41	1
Ontonagon	12	42	1	12	44	1	24	43	1
Upper Portage Entry	6	43	1	6	43	0	12	43	1
Lower Portage Entry	6	42	1	6	43	2	12	42	1
Eagle Harbor	2	41	0	2	42	1	4	41	1
Isle Royale	6	44	1	4	43	1	10	43	1
Big Bay	6	43	1	4	43	1	10	43	1
Presque Isle (Marquette)	12	42	2	12	42	1	24	42	2
Carp River (Marquette)	11	40	2	12	42	1	23	41	1
Munising	12	45	2	12	43	0	24	43	2
Grand Marais	4	43	1	4	42	1	8	42	1
Whitefish Point	4	44		4	41	1	8	43	1
Lake Huron									
Detour	4	65	6	4	65	8	8	65	6
Cheboygan	12	96	1	12	95	2	24	96	2
Presque Isle	4	82	4	4	78	0	8	80	3
Alpena	12	100	8	12	87	3	24	93	9
Harrisville	4	79	2	4	79	2	8	79	0
Tawas	12	80	2	12	83	1	24	81	2
Saginaw Bay	6	91	7	6	84	4	12	87	7
Harbor Beach	12	82	1	12	81	1	24	82	1
Lexington	4	83	2	4	80	1	8	81	2

Hardness (mg/l)

Lake Superior	SPRING n	SPRING X̄	SPRING SD	FALL n	FALL X̄	FALL SD	ANNUAL n	ANNUAL X̄	ANNUAL SD
Black River	4	44	1	4	46	0	8	45	1
Ontonagon	12	44	1	12	48	1	24	46	1
Upper Portage Entry	6	45	1	6	46	1	12	46	1
Lower Portage Entry	6	45	1	6	45	1	12	45	1
Eagle Harbor	2	45	0	2	46	1	4	45	1
Isle Royale	6	45	0	4	46	1	10	45	0
Big Bay	6	45	2	4	45	1	10	45	2
Presque Isle (Marquette)	12	44	1	12	45	1	24	45	1
Carp River (Marquette)	11	45	1	12	46	1	23	45	1
Munising	12	45	2	12	45	1	24	45	1
Grand Marais	4	45	1	4	47	2	8	46	2
Whitefish Point	4	45	1	4	46	1	8	45	1
Lake Huron									
Detour	4	79	15	4	80	10	8	79	13
Cheboygan	12	117	2	12	115	1	24	116	2
Presque Isle	4	103	4	4	95	0	8	99	5
Alpena	12	119	13	12	106	3	24	113	9
Harrisville	4	98	2	4	97	1	8	97	2
Tawas	12	99	1	12	100	2	24	100	1
Saginaw Bay	6	145	14	6	100	6	12	122	25
Harbor Beach	12	104	2	12	102	2	24	103	2
Lexington	4	103	2	4	98	1	8	100	1

continued

Table A-3 (continued)

Magnesium (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	4	3.0	0.1	4	3.3	0.0	8	3.2	0.1
Ontonagon	12	3.0	0.1	12	3.4	0.1	24	3.2	0.2
Upper Portage Entry	6	3.0	0.1	6	3.1	0.1	12	3.0	0.1
Lower Portage Entry	6	3.0	0.0	6	3.2	0.0	12	3.1	0.1
Eagle Harbor	2	3.3	0.0	2	3.2	0.0	4	3.3	0.1
Isle Royale	6	3.2	0.1	4	3.2	0.0	10	3.2	0.1
Big Bay	6	3.0	0.0	4	3.2	0.1	10	3.1	0.1
Presque Isle (Marquette)	12	3.0	0.1	12	3.3	0.0	24	3.2	0.1
Carp River (Marquette)	11	3.1	0.1	12	3.3	0.1	23	3.2	0.1
Munising	11	3.1	0.1	12	3.2	0.0	23	3.2	0.1
Grand Marais	4	3.1	0.1	4	3.1	0.0	8	3.1	0.0
Whitefish Point	4	3.1	0.1	4	3.2	0.0	8	3.1	0.1
Lake Huron									
Detour	4	6.3	0.7	4	6.4	1.0	8	6.4	0.9
Cheboygan	12	10.0	0.0	12	9.9	0.1	24	10.0	0.1
Presque Isle	4	8.1	0.3	4	7.8	0.1	8	7.9	0.3
Alpena	12	8.9	0.5	12	8.3	0.2	24	8.6	0.5
Harrisville	4	8.0	0.1	4	7.7	0.1	8	7.8	0.2
Tawas	12	7.8	0.1	12	7.7	0.0	24	7.8	0.1
Saginaw Bay	6	9.7	1.1	6	8.4	0.5	12	9.0	1.0
Harbor Beach	12	8.0	0.1	12	7.8	0.2	24	7.9	0.1
Lexington	4	8.4	0.1	4	7.7	0.0	8	8.0	0.3

Calcium (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	4	13	0	4	13	0	8	13	0
Ontonagon	12	13	0	12	14	0	24	14	1
Upper Portage Entry	6	14	0	6	14	1	12	14	0
Lower Portage Entry	6	13	0	6	14	0	12	14	0
Eagle Harbor	2	14	0	2	14	0	4	14	0
Isle Royale	6	13	0	4	14	1	10	14	0
Big Bay	6	14	0	4	13	0	10	14	1
Presque Isle (Marquette)	12	14	0	12	14	0	24	14	0
Carp River (Marquette)	11	14	0	12	14	1	23	14	0
Munising	12	13	0	12	14	1	24	13	0
Grand Marais	4	14	0	4	13	0	8	13	0
Whitefish Point	4	13	0	4	13	1	8	13	0
Lake Huron									
Detour	4	22	2	4	22	3	8	22	3
Cheboygan	12	31	1	12	30	0	24	31	1
Presque Isle	4	27	1	4	26	0	8	27	1
Alpena	12	33	2	12	29	0	24	31	3
Harrisville	4	27	1	4	28	1	8	28	1
Tawas	12	28	1	12	27	1	24	28	1
Saginaw Bay	6	27	3	6	30	2	12	28	3
Harbor Beach	12	29	1	12	28	0	24	28	1
Lexington	4	29	1	4	27		8	28	1

continued

Table A-3 (continued)

Potassium (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	4	0.40	0.01	4	0.52	0.06	8	0.47	0.07
Ontonagon	12	0.41	0.01	12	0.56	0.10	24	0.49	0.10
Upper Portage Entry	6	0.45	0.08	6	0.51	0.06	12	0.48	0.08
Lower Portage Entry	6	0.49	0.06	6	0.46	0.02	12	0.48	0.04
Eagle Harbor	2	0.46	0.01	2	0.54	0.09	4	0.50	0.08
Isle Royale	6	0.42	0.03	4	0.52	0.02	10	0.46	0.06
Big Bay	6	0.47	0.01	4	0.58	0.10	10	0.52	0.08
Presque Isle (Marquette)	12	0.47	0.03	12	0.45	0.01	24	0.46	0.02
Carp River (Marquette)	11	0.44	0.02	12	0.45	0.01	23	0.44	0.02
Munising	11	0.42	0.04	12	0.57	0.15	23	0.51	0.14
Grand Marais	4	0.41	0.02	4	0.47	0.01	8	0.44	0.03
Whitefish Point	4	0.38	0.01	4	0.44	0.01	8	0.41	0.03
Lake Huron									
Detour	4	0.58	0.05	4	0.64	0.09	8	0.61	0.08
Cheboygan	12	0.81	0.03	12	0.86	0.02	24	0.84	0.04
Presque Isle	4	0.66	0.02	4	0.76	0.01	8	0.71	0.05
Alpena	12	0.85	0.21	12	0.79	0.02	24	0.82	0.15
Harrisville	4	0.68	0.01	4	0.72	0.01	8	0.70	0.02
Tawas	12	0.76	0.03	12	0.87	0.12	24	0.82	0.10
Saginaw Bay	6	1.05	0.16	6	0.90	0.08	12	0.98	0.15
Harbor Beach	12	0.80	0.02	12	0.84	0.08	24	0.82	0.06
Lexington	4	0.79	0.04	4	0.85	0.03	8	0.82	0.04

Sodium (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	4	1.3	0.1	4	1.6	0.2	8	1.4	0.2
Ontonagon	12	1.4	0.1	12	1.9	0.5	24	1.6	0.4
Upper Portage Entry	6	1.5	0.3	6	1.7	0.3	12	1.6	0.3
Lower Portage Entry	6	1.3	0.1	6	1.6	0.1	12	1.5	0.2
Eagle Harbor	2	1.7	0.1	2	1.9	0.4	4	1.8	0.3
Isle Royale	6	2.3	0.4	4	1.4	0.1	10	1.9	0.6
Big Bay	6	1.2	0.1	4	1.6	0.3	10	1.3	0.3
Presque Isle (Marquette)	12	1.3	0.1	12	1.8	0.3	24	1.5	0.4
Carp River (Marquette)	11	3.1	0.1	12	1.6	0.2	23	2.4	0.8
Munising	11	1.3	0.1	12	1.6	0.3	23	1.4	0.3
Grand Marais	4	1.2	0.0	4	1.5	0.1	8	1.3	0.1
Whitefish Point	4	1.2	0.1	4	1.3	0.1	8	1.3	0.1
Lake Huron									
Detour	4	3.7	0.4	4	2.6	0.5	8	3.2	0.7
Cheboygan	12	4.9	0.3	12	4.1	0.1	24	4.5	0.5
Presque Isle	4	3.9	0.2	4	3.2	0.1	8	3.5	0.4
Alpena	12	4.5	0.5	12	3.6	0.1	24	4.0	0.6
Harrisville	4	4.1	0.2	4	3.3	0.1	8	3.7	0.4
Tawas	12	4.3	0.2	12	3.8	0.3	24	4.1	0.4
Saginaw Bay	6	5.8	1.4	6	4.6	1.0	12	5.2	1.4
Harbor Beach	12	5.0	0.2	12	3.8	0.5	24	4.4	0.7
Lexington	4	5.5	0.1	4	3.4	0.1	8	4.5	1.1

continued

Table A-3 (continued)

Chloride (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\overline{X}$	SD	n	$\overline{X}$	SD	n	$\overline{X}$	SD
Black River	4	1.3	0.1	4	1.2	0.0	8	1.3	0.1
Ontonagon	12	1.5	0.3	12	1.4	0.1	24	1.4	0.2
Upper Portage Entry	6	1.0	0.0	6	1.2	0.0	12	1.1	0.1
Lower Portage Entry	6	1.2	0.4	6	1.2	0.1	12	1.2	0.3
Eagle Harbor	2	1.4	1.0	2	1.1	0.0	4	1.2	0.1
Isle Royale	6	1.1	0.0	4	1.2	0.1	10	1.1	0.1
Big Bay	6	0.9	0.2	4	1.3	0.1	10	1.1	0.2
Presque Isle (Marquette)	12	0.6	0.2	12	1.3	0.1	24	0.9	0.4
Carp River (Marquette)	11	1.5	0.1	12	1.3	0.2	23	1.4	0.2
Munising	12	1.3	0.3	12	1.1	0.1	24	1.2	0.3
Grand Marais	4	1.4	0.1	4	1.3	0.1	8	1.3	0.1
Whitefish Point	4	1.0	0.1	4	1.1	0.0	8	1.1	0.0
Lake Huron									
Detour	4	3.5	0.6	4	4.0	0.9	8	3.8	0.8
Cheboygan	12	6.2	0.1	12	7.5	0.1	24	6.8	0.7
Presque Isle	4	4.3	0.2	4	5.8	0.1	8	5.3	0.5
Alpena	12	4.8	0.2	12	5.9	0.1	24	5.3	0.6
Harrisville	4	5.2	0.2	4	5.8	0.1	8	5.5	0.3
Tawas	12	5.6	0.2	12	6.8	0.8	24	6.2	0.9
Saginaw Bay	6	11.0	3.6	6	8.8	2.5	12	9.9	3.3
Harbor Beach	12	7.0	0.2	12	6.5	0.2	24	6.8	0.3
Lexington	4	6.7	0.7	4	5.8	0.1	8	6.2	0.6

Sulfate (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\overline{X}$	SD	n	$\overline{X}$	SD	n	$\overline{X}$	SD
Black River	4	2.8	0.2	4	2.9	0.2	8	2.8	0.2
Ontonagon	12	3.1	0.3	12	2.9	0.3	24	3.0	0.3
Upper Portage Entry	6	2.9	0.2	6	2.0	0.1	12	2.5	0.5
Lower Portage Entry	6	2.3	0.4	6	3.0	0.2	12	3.0	0.3
Eagle Harbor	2	2.8	0.1	2	3.5	0.4	4	3.1	0.4
Isle Royale	6	3.2	0.1	4	3.3	0.4	10	3.2	0.3
Big Bay	6	2.7	0.2	4	2.5	0.2	10	2.6	0.2
Presque Isle (Marquette)	12	3.1	0.4	12	3.0	0.3	24	3.1	0.3
Carp River (Marquette)	11	2.6	0.2	12	2.9	0.1	23	2.8	0.3
Munising	12	3.2	0.4	12	2.9	0.3	24	3.0	0.3
Grand Marais	4	2.9	0.2	4	2.6	0.3	8	2.8	0.3
Whitefish Point	4	2.8	0.5	4	2.4	0.2	8	2.6	0.4
Lake Huron									
Detour	4	11.2	2.3	4	10.4	2.8	8	10.8	2.6
Cheboygan	12	16.6	0.7	12	16.3	0.5	24	16.5	0.6
Presque Isle	4	13.8	0.5	4	12.8	0.5	8	13.3	0.7
Alpena	12	26.7	2.0	12	14.1	1.0	24	20.4	6.5
Harrisville	4	14.0	0.0	4	14.8	0.5	8	14.4	0.5
Tawas	12	14.0	0.9	12	15.0	0.4	24	15.5	0.8
Saginaw Bay	6	18.7	2.5	6	19.0	2.1	12	18.9	2.3
Harbor Beach	12	17.5	0.5	12	16.2	0.4	24	16.8	0.8
Lexington	4	17.0	0.8	4	13.8	0.5	8	15.4	1.8

continued

Table A-3 (continued)

Total Dissolved Solids (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	4	53	1	4	52	0	8	52	0
Ontonagon	12	53	1	12	55	2	24	54	2
Upper Portage Entry	6	54	1	6	53	0	12	53	1
Lower Portage Entry	6	53	2	6	54	1	12	54	1
Eagle Harbor	2	54	0	2	54	1	4	54	1
Isle Royale	6	55	1	4	54	1	10	55	1
Big Bay	6	53	1	4	54	1	10	53	1
Presque Isle (Marquette)	12	52	1	12	53	1	24	53	1
Carp River (Marquette)	11	52	1	12	53	1	23	53	1
Munising	11	55	2	12	53	1	23	54	2
Grand Marais	4	54	1	4	53	1	8	53	1
Whitefish Point	4	53	1	4	51	1	8	52	1
Lake Huron									
Detour	4	93	10	4	91	13	8	92	12
Cheboygan	12	135	1	12	134	2	24	135	2
Presque Isle	4	115	4	4	111	1	8	113	4
Alpena	12	149	8	12	121	3	24	135	15
Harrisville	4	113	2	4	114	1	8	114	2
Tawas	12	116	2	12	118	2	24	117	3
Saginaw Bay	6	136	16	6	129	11	12	133	14
Harbor Beach	12	124	2	12	119	1	24	121	3
Lexington	4	124	3	4	113	1	8	119	6

Conductivity (μ-mho/cm)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	18	87	2	17	89	1	35	88	2
Ontonagon	18	88	2	18	92	5	36	90	4
Upper Portage Entry	9	86	1	9	88	0	18	87	2
Lower Portage Entry	9	85	3	9	83	1	18	86	3
Eagle Harbor	9	85	3	7	88	1	16	86	3
Isle Royale	6	87	1	3	88	3	9	87	2
Big Bay	18	85	1	17	87	1	35	86	1
Presque Isle (Marquette)	17	85	1	14	88	2	31	87	2
Carp River (Marquette)	15	87	1	15	88	1	30	88	1
Munising	18	88	3	18	87	2	36	88	3
Grand Marais	18	87	1	18	87	1	36	87	1
Whitefish Point	14	87	1	15	87	1	29	87	1
Lake Huron									
Detour	18	155	11	18	153	18	36	154	15
Cheboygan	18	228	4	18	222	2	36	225	4
Presque Isle	17	191	6	17	86	2	34	189	5
Alpena	18	224	11	18	203	4	36	213	13
Harrisville	18	190	6	18	190	2	36	190	5
Tawas	17	195	1	18	196	2	35	196	2
Saginaw Bay	8	232	29	8	205	12	16	219	26
Harbor Beach	16	202	4	15	145	3	31	199	5
Lexington	18	207	9	18	189	0	36	198	11

continued

Table A-3 (continued)

Total Phosphorus (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\overline{X}$	SD	n	$\overline{X}$	SD	n	$\overline{X}$	SD
Black River	18	0.006	0.005	18	0.007	0.002	36	0.006	0.004
Ontonagon	18	0.006	0.012	18	0.004	0.002	36	0.005	0.009
Upper Portage Entry	9	0.004	0.001	9	0.002	0.001	18	0.003	0.005
Lower Portage Entry	9	CONTAMINATED		9	0.005	0.001	18	------	------
Eagle Harbor	9	0.004	0.002	9	0.006	0.006	18	0.005	0.004
Isle Royale	9	0.004	0.005	6	0.005	0.003	15	0.005	0.004
Big Bay	18	0.005	0.009	18	0.008	0.003	36	0.007	0.006
Presque Isle (Marquette)	17	0.004	0.002	14	0.005	0.003	33	0.004	0.003
Carp River (Marquette)	16	0.006	0.002	15	0.012	0.003	31	0.009	0.004
Munising	18	0.010	0.013	17	0.007	0.005	35	0.008	0.010
Grand Marais	18	0.002	0.001	18	0.004	0.002	36	0.003	0.002
Whitefish Point	18	<0.002	------	18	0.004	0.002	36	------	------
Lake Huron									
Detour	18	0.007	0.002	18	0.008	0.001	36	0.007	0.002
Cheboygan	18	0.005	0.004	18	0.005	0.001	36	0.005	0.003
Presque Isle	18	0.006	0.006	17	0.003	0.002	35	0.005	0.005
Alpena	18	0.036	0.053	18	0.021	0.005	36	0.028	0.039
Harrisville	18	0.005	0.002	18	0.007	0.002	36	0.008	0.003
Tawas	18	0.010	0.003	18	0.006	0.001	36	0.008	0.003
Saginaw Bay	8	0.018	0.011	8	0.021	0.018	16	0.019	0.015
Harbor Beach	15	0.016	0.006	15	0.008	0.004	30	0.012	0.007
Lexington	18	0.011	0.004	18	0.006	0.001	36	0.008	0.004

Total Ortho-Phosphate (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\overline{X}$	SD	n	$\overline{X}$	SD	n	$\overline{X}$	SD
Black River	18	0.001	0.000	18	0.003	0.002	36	0.002	0.002
Ontonagon	18	0.003	0.006	18	0.002	0.001	36	0.003	0.004
Upper Portage Entry	9	0.003	0.001	9	0.001	0.000	18	0.002	0.001
Lower Portage Entry	9	CONTAMINATED?		9	0.001	0.000	18	--	--
Eagle Harbor	9	0.001	0.001	9	0.001	0.000	18	0.001	0.001
Isle Royale	9	0.001	0.000	6	0.001	0.001	15	0.001	0.000
Big Bay	18	0.001	0.001	18	0.003	0.001	36	0.002	0.002
Presque Isle (Marquette)	17	0.001	0.000	14	0.002	0.001	31	0.001	0.001
Carp River (Marquette)	15	0.001	0.001	15	0.002	0.001	30	0.002	0.001
Munising	18	0.002	0.002	18	0.001	0.001	36	0.001	0.001
Grand Marais	18	0.001	0.000	18	0.002	0.001	36	0.002	0.001
Whitefish Point	18	0.001	0.001	18	0.002	0.001	36	0.002	0.001
Lake Huron									
Detour	18	0.003	0.001	18	0.003	0.001	36	0.003	0.002
Cheboygan	18	0.001	0.001	18	0.002	0.001	36	0.002	0.001
Presque Isle	18	0.001	0.001	17	0.002	0.001	35	0.001	0.001
Alpena	18	0.007	0.010	18	0.007	0.002	36	0.007	0.007
Harrisville	18	0.001	0.000	18	0.002	0.001	36	0.006	0.001
Tawas	18	0.002	0.001	18	0.001	0.001	36	0.002	0.001
Saginaw Bay	8	0.003	0.002	8	0.006	0.001	16	0.004	0.002
Harbor Beach	16	0.005	0.001	14	0.002	0.001	30	0.004	0.002
Lexington	18	0.004	0.001	18	0.003	0.001	36	0.004	0.001

continued

Table A-3 (continued)

Nitrite-Nitrogen (mg/1)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	18	0.001	0.001	18	0.002	0.000	36	0.002	0.001
Ontonagon	18	0.001	0.001	18	0.002	0.001	36	0.002	0.001
Upper Portage Entry	9	0.001	0.001	9	0.002	0.001	18	0.002	0.001
Lower Portage Entry	9	0.002	0.001	9	0.001	0.001	18	0.002	0.001
Eagle Harbor	9	0.002	0.001	9	0.002	0.000	18	0.002	0.001
Isle Royale	9	0.001	0.000	6	0.002	0.001	15	0.002	0.001
Big Bay	18	0.001	0.000	18	0.002	0.000	36	0.002	0.000
Presque Isle (Marquette)	17	0.002	0.001	14	0.001	0.000	31	0.002	0.001
Carp River (Marquette)	15	0.002	0.001	15	0.001	0.000	30	0.001	0.000
Munising	18	0.001	0.000	18	0.002	0.000	36	0.002	0.001
Grand Marais	18	0.002	0.001	18	0.001	0.000	36	0.002	0.001
Whitefish Point	18	0.001	0.000	18	0.004	0.000	36	0.003	0.002
Lake Huron									
Detour	18	0.001	0.000	18	0.004	0.002	36	0.003	0.002
Cheboygan	18	0.002	0.001	18	0.002	0.001	36	0.002	0.001
Presque Isle	18	0.002	0.000	17	0.002	0.001	35	0.002	0.000
Alpena	18	0.002	0.002	18	0.001	0.001	36	0.002	0.001
Harrisville	18	0.001	0.001	18	0.002	0.000	36	0.002	0.001
Tawas	18	0.002	0.001	18	0.002	0.001	36	0.002	0.001
Saginaw Bay	8	0.007	0.001	8	0.006	0.001	16	0.006	0.001
Harbor Beach	16	0.005	0.001	14	0.003	0.000	30	0.004	0.001
Lexington	18	0.004	0.000	18	0.002	0.001	36	0.003	0.001

Nitrate-Nitrogen (mg/1)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	18	0.255	0.028	18	0.273	0.069	36	0.264	0.053
Ontonagon	18	0.248	0.008	18	0.240	0.019	36	0.244	0.015
Upper Portage Entry	9	0.268	0.006	9	0.260	0.052	18	0.264	0.037
Lower Portage Entry	9	0.261	0.012	9	0.287	0.046	18	0.274	0.036
Eagle Harbor	9	0.250	0.007	9	0.272	0.026	18	0.261	0.021
Isle Royale	9	0.263	0.005	6	0.296	0.054	15	0.277	0.038
Big Bay	18	0.311	0.109	18	0.341	0.181	36	0.326	0.150
Presque Isle (Marquette)	17	0.274	0.012	14	0.282	0.023	31	0.278	0.018
Carp River (Marquette)	15	0.236	0.009	15	0.242	0.005	30	0.239	0.007
Munising	18	0.252	0.006	18	0.277	0.046	36	0.265	0.035
Grand Marais	18	0.272	0.004	18	0.264	0.058	36	0.268	0.041
Whitefish Point	18	0.251	0.005	18	0.291	0.047	36	0.272	0.038
Lake Huron									
Detour	18	0.263	0.028	18	0.265	0.020	36	0.264	0.024
Cheboygan	18	0.167	0.015	18	0.165	0.019	36	0.166	0.017
Presque Isle	18	0.227	0.044	17	0.207	0.019	35	0.218	0.035
Alpena	18	0.138	0.016	18	0.142	0.014	36	0.140	0.015
Harrisville	18	0.216	0.060	18	0.215	0.024	36	0.216	0.045
Tawas	18	0.211	0.014	18	0.226	0.055	36	0.219	0.040
Saginaw Bay	8	0.172	0.061	8	0.143	0.086	16	0.158	0.075
Harbor Beach	16	0.256	0.006	14	0.213	0.009	30	0.237	0.022
Lexington	18	0.264	0.010	18	0.231	0.042	36	0.248	0.034

continued

Table A-3 (continued)

Ammonia-Nitrogen (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	18	0.006	0.002	18	0.002	0.001	36	0.004	0.002
Ontonagon	18	0.006	0.002	18	0.006	0.002	36	0.006	0.002
Upper Portage Entry	9	0.003	0.002	9	0.003	0.002	18	0.003	0.002
Lower Portage Entry	9	0.012	0.007	9	0.007	0.002	18	0.010	0.006
Eagle Harbor	9	0.005	0.001	9	0.005	0.001	18	0.005	0.001
Isle Royale	9	0.003	0.001	6	0.009	0.002	15	0.006	0.003
Big Bay	18	0.001	0.002	18	0.006	0.001	36	0.005	0.003
Presque Isle (Marquette)	17	0.001	0.000	14	0.008	0.003	31	0.005	0.004
Carp River (Marquette)	15	0.005	0.002	15	0.008	0.003	30	0.007	0.003
Munising	18	0.004	0.005	18	0.008	0.005	36	0.006	0.006
Grand Marais	18	0.005	0.001	18	0.007	0.002	36	0.006	0.002
Whitefish Point	18	0.002	0.002	18	0.014	0.003	36	0.010	0.007
Lake Huron									
Detour	18	0.012	0.009	18	0.014	0.006	36	0.013	0.008
Cheboygan	18	0.003	0.002	18	0.004	0.002	36	0.004	0.002
Presque Isle	18	0.003	0.002	17	0.001	0.001	35	0.002	0.002
Alpena	18	0.006	0.005	18	0.022	0.007	36	0.016	0.010
Harrisville	18	0.004	0.001	18	0.006	0.002	36	0.005	0.002
Tawas	18	0.005	0.001	18	0.011	0.003	36	0.008	0.003
Saginaw Bay	8	0.022	0.018	8	0.008	0.005	16	0.016	0.015
Harbor Beach	16	0.038	0.011	14	0.012	0.009	30	0.029	0.016
Lexington	18	0.032	0.014	18	0.005	0.001	36	0.023	0.017

Organic Nitrogen (mg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	18	0.11	0.03	18	0.09	0.02	36	0.10	0.03
Ontonagon	18	0.12	0.04	18	0.10	0.03	36	0.08	0.04
Upper Portage Entry	9	0.19	0.02	9	0.10	0.02	18	0.14	0.05
Lower Portage Entry	9	0.15	0.06	9	0.13	0.02	18	0.14	0.05
Eagle Harbor	9	0.12	0.10	9	0.13	0.02	18	0.13	0.07
Isle Royale	9	0.12	0.07	6	0.08	0.02	15	0.10	0 06
Big Bay	18	0.15	0.04	18	0.11	0.06	36	0.13	0.05
Presque Isle (Marquette)	17	0.09	0.04	14	0.11	0.04	31	0.10	0.04
Carp River (Marquette)	15	0.14	0.03	15	0.12	0.05	30	0.13	0.04
Munising	18	0.18	0.08	18	0.11	0.05	36	0.15	0.08
Grand Marais	18	0.12	0.04	18	0.11	0.02	36	0.11	0.03
Whitefish Point	18	0.08	0.06	18	0.11	0.03	36	0.10	0.05
Lake Huron									
Detour	18	0.28	0.10	18	0.18	0.05	36	0.23	0.09
Cheboygan	18	0.14	0.02	18	0.16	0.04	36	0.15	0.03
Presque Isle	18	0.14	0.05	17	0.15	0.04	36	0.14	0.05
Alpena	18	0.36	0.08	18	0.25	0.03	36	0.21	0.08
Harrisville	18	0.16	0.05	18	0.24	0.04	36	0.20	0.06
Tawas	18	0.21	0.06	18	0.20	0.08	36	0.21	0.07
Saginaw Bay	8	0.29	0.09	8	0.29	0.13	16	0.29	0.11
Harbor Beach	16	0.28	0.09	15	0.11	0.04	31	0.20	0.11
Lexington	18	0.22	0.18	18	0.24	0.03	36	0.23	0.13

continued

Table A-3 (continued)

REACTIVE SILICA (mg/1)

Lake Superior	SPRING			FALL			ANNUAL		
	N	$\overline{X}$	SD	N	$\overline{X}$	SD	N	$\overline{X}$	SD
Black River	4	2.5	0.2	4	2.1	0.1	8	2.3	0.2
Ontonagon	12	2.8	0.1	12	2.4	0.3	24	2.6	0.3
Upper Portage Entry	6	2.6	0.1	6	2.1	0.1	12	2.4	0.3
Lower Portage Entry	6	2.4	0.4	6	2.2	0.0	12	2.5	0.5
Eagle Harbor	4	3.4	0.1	2	1.7	0.8	4	2.5	1.1
Isle Royale	6	2.6	0.0	4	2.1	0.1	10	2.5	0.2
Big Bay	6	2.6	0.2	4	2.3	0.1	10	2.5	0.2
Presque Isle (Marquette)	12	2.6	0.2	12	2.2	0.0	24	2.4	0.3
Carp River (Marquette)	11	2.3	0.0	11	2.2	0.0	22	2.3	0.0
Munising	12	2.5	0.3	12	2.3	0.1	24	2.4	0.3
Grand Marais	5	2.0	0.9	4	2.1	0.0	9	2.0	0.6
Whitefish Point	4	2.4	0.1	4	2.8	0.1	8	2.3	0.1
Lake Huron									
Detour	4	1.5	0.2	4	1.8	0.1	8	1.6	0.2
Cheboygan	12	0.6	0.2	12	0.9	0.0	24	0.8	0.2
Presque Isle	3	1.2	0.3	4	0.8	0.1	7	1.0	0.3
Alpena	12	1.0	0.2	12	2.4	0.8	24	1.7	0.9
Harrisville	4	1.3	0.4	4	0.7	0.1	8	1.0	0.4
Tawas	11	1.2	0.3	12	0.7	0.0	23	1.0	0.3
Saginaw Bay	6	0.6	0.1	5	1.0	0.2	11	0.9	0.2
Harbor Beach	13	0.9	0.1	12	0.6	0.1	25	0.7	0.2
Lexington	4	0.9	0.3	4	0.4	0.0	8	0.7	0.3

Total Nitrogen (mg/1)

Lake Superior	SPRING			FALL			ANNUAL		
	n	$\overline{X}$	SD	n	$\overline{X}$	SD	n	$\overline{X}$	SD
Black River	18	0.37	0.04	18	0.36	0.09	36	0.37	0.07
Ontonagon	18	0.38	0.04	18	0.38	0.03	36	0.36	0.04
Upper Portage Entry	9	0.45	0.02	9	0.36	0.06	18	0.41	0.06
Lower Portage Entry	9	0.42	0.05	9	0.43	0.06	18	0.42	0.05
Eagle Harbor	9	0.37	0.10	9	0.41	0.03	18	0.39	0.08
Isle Royale	9	0.39	0.07	6	0.39	0.06	15	0.39	0.07
Big Bay	18	0.46	0.12	18	0.46	0.23	36	0.46	0.18
Presque Isle (Marquette)	17	0.36	0.04	14	0.40	0.05	31	0.38	0.05
Carp River (Marquette)	15	0.38	0.03	15	0.38	0.05	30	0.38	0.04
Munising	18	0.44	0.08	18	0.39	0.06	36	0.42	0.08
Grand Marais	18	0.39	0.05	18	0.38	0.07	36	0.39	0.06
Whitefish Point	18	0.32	0.04	18	0.44	0.12	36	0.38	0.11
Lake Huron									
Detour	18	0.56	0.10	17	0.46	0.05	35	0.51	0.09
Cheboygan	18	0.32	0.02	18	0.33	0.05	36	0.32	0.04
Presque Isle	18	0.37	0.08	17	0.36	0.05	35	0.36	0.30
Alpena	18	0.51	0.08	18	0.42	0.03	36	0.46	0.08
Harrisville	18	0.38	0.09	18	0.47	0.05	36	0.42	0.08
Tawas	18	0.43	0.05	18	0.42	0.06	36	0.43	0.06
Saginaw Bay	8	0.49	0.05	8	0.44	0.05	16	0.47	0.05
Harbor Beach	16	0.58	0.09	15	0.34	0.04	31	0.46	0.43
Lexington	18	0.45	0.05	18	0.47	0.05	36	0.46	0.05

continued

Table A-3 (continued)

Chlorophyll a (μg/l)

Lake Superior	SPRING n	SPRING X̄	SPRING SD	FALL n	FALL X̄	FALL SD	ANNUAL n	ANNUAL X̄	ANNUAL SD
Black River	2	2.6	0.7	2	2.0	0.0	4	2.3	0.6
Ontonagon	6	1.6	0.7	6	1.6	0.4	12	1.6	0.5
Upper Portage Entry	3	2.8	0.2	3	0.9	0.1	6	1.9	0.9
Lower Portage Entry	3	1.4	0.2	3	1.9	0.6	6	1.7	0.5
Eagle Harbor	1	1.9	0.0	1	2.4	0.0	2	2.1	0.2
Isle Royale	3	0.8	0.1	2	2.4	0.6	5	1.5	0.9
Big Bay	2	1.6	0.2	2	0.6	0.3	4	1.1	0.6
Presque Isle (Marquette)	6	1.9	0.8	5	1.2	0.4	11	1.6	0.7
Carp River (Marquette)	3	1.4	0.1	6	1.1	0.4	9	1.2	0.4
Munising	6	1.8	0.3	6	1.3	0.3	12	1.5	0.4
Grand Marais	2	1.4	0.0	2	1.1	0.3	4	1.2	0.2
Whitefish Point	2	1.5	0.1	2	0.7	0.1	4	1.1	0.5
Lake Huron									
Detour	2	1.7	0.2	2	1.8	0.6	4	1.8	0.5
Cheboygan	6	1.5	0.3	6	2.6	1.7	12	2.1	1.4
Presque Isle	2	1.4	0.1	2	2.0	0.2	4	1.3	0.3
Alpena	7	10.6	4.2	6	6.5	2.2	13	8.7	4.0
Harrisville	1	3.1	-	2	3.1	0.2	3	3.1	0.2
Tawas	6	3.6	1.7	6	3.3	0.7	12	3.5	1.3
Saginaw Bay	2	6.1	4.9	3	5.7	6.6	5	5.9	0.3
Harbor Beach	4	4.5	0.8	6	6.2	0.6	10	5.4	1.2
Lexington	2	5.3	0.2	2	2.6	0.2	4	3.9	1.4

Copper (μg/l)

Lake Superior	SPRING n	SPRING X̄	SPRING SD	FALL n	FALL X̄	FALL SD	ANNUAL n	ANNUAL X̄	ANNUAL SD
Black River	12	5 *	5	12	2	1	24	3	4
Ontonagon	12	4	3	12	2	1	24	3	3
Upper Portage Entry	6	3	2	6	4	2	12	3	2
Lower Portage Entry	6	14 *	5	6	2	1	12	8*	7
Eagle Harbor	6	10 *	4	6	2	1	12	6*	5
Isle Royale	6	4	4	4	4	1	10	4	3
Big Bay	12	8 *	4	12	3	3	24	6*	4
Presque Isle (Marquette)	12	6 *	3	12	3	1	24	4	3
Carp River (Marquette)	12	3	5	12	2	0	24	3	3
Munising	12	3	3	12	3	1	24	3	1
Grand Marais	12	3	1	12	2	1	24	3	1
Whitefish Point	12	7 *	4	12	2	1	24	4	4
Lake Huron									
Detour	12	5 *	3	12	2	1	24	3	3
Cheboygan	12	5 *	1	12	1	1	24	3	2
Presque Isle	12	2	2	12	8 *	20	24	5	14
Alpena	12	2	3	12	3	2	24	3	3
Harrisville	12	4	2	12	3	3	24	3	2
Tawas	12	13 *	9	12	4	5	24	8	8
Saginaw Bay	6	2	2	6	4	1	12	3	2
Harbor Beach	12	2	1	12	2	1	24	2	1
Lexington	12	1	1	12	2	1	24	2	1

continued

Table A-3 (continued)

Iron (μg/l)

Lake Superior	SPRING n	SPRING $\overline{X}$	SPRING SD	FALL n	FALL $\overline{X}$	FALL SD	ANNUAL n	ANNUAL $\overline{X}$	ANNUAL SD
Black River	12	86	49	12	42	33	24	64	47
Ontonagon	12	58	27	12	64	50	24	61	39
Upper Portage Entry	6	40	13	6	62	70	12	51	49
Lower Portage Entry	6	37	49	6	27	26	12	32	38
Eagle Harbor	6	48	13	6	18	6	12	33	18
Isle Royale	6	23	24	4	11	2	10	18	19
Big Bay	12	8	7	12	55	89	24	31	67
Presque Isle (Marquette)	12	37	35	12	22	13	24	30	27
Carp River (Marquette)	12	25	12	12	19	9	24	22	11
Munising	12	56	55	12	54	86	24	55	70
Grand Marais	12	17	14	12	14	4	24	16	10
Whitefish Point	12	17	6	12	23	28	24	20	20
Lake Huron									
Detour	12	34	17	12	66	24	24	50	26
Cheboygan	12	26	16	12	22	5	24	24	12
Presque Isle	12	168	261	12	21	19	24	95	196
Alpena	12	82	262	12	84	28	24	133	189
Harrisville	12	12	5	12	25	20	24	18	16
Tawas	12	20	5	12	16	4	24	18	5
Saginaw Bay	6	61	33	6	84	66	12	73	51
Harbor Beach	12	228	138	12	184	271	24	206	211
Lexington	12	59	34	12	34	12	24	47	28

Manganese (μg/l)

Lake Superior	SPRING n	SPRING $\overline{X}$	SPRING SD	FALL n	FALL $\overline{X}$	FALL SD	ANNUAL n	ANNUAL $\overline{X}$	ANNUAL SD
Black River	12	3	2	12	2	2	24	3	2
Ontonagon	12	2	1	12	4	3	24	3	2
Upper Portage Entry	6	2	1	6	2	2	12	2	1
Lower Portage Entry	6	3	2	6	1	1	12	2	2
Eagle Harbor	6	2	1	6	1	0	12	2	1
Isle Royale	6	1	0	4	1	0	10	1	0
Big Bay	12	<1	-	12	2	3	24	2	2
Presque Isle (Marquette)	12	2	3	12	2	2	24	2	2
Carp River (Marquette)	12	4	2	12	2	2	24	3	2
Munising	12	3	3	12	2	3	24	3	3
Grand Marais	12	1	0	12	<1	-	24	<1	-
Whitefish Point	12	1	0.	12	2	2	24	1	1
Lake Huron									
Detour	12	2	1	12	3	1	24	3	1
Cheboygan	12	2	0	12	2	0	24	2	0
Presque Isle	12	8	13	12	2	1	24	5	10
Alpena	12	15	16	12	7	2	24	11	12
Harrisville	12	2	1	12	2	1	24	2	8
Tawas	12	2	1	12	2	1	24	2	1
Saginaw Bay	6	6	2	6	6	4	12	6	3
Harbor Beach	12	9	5	12	6	5	24	8	5
Lexington	12	3	1	12	2	1	24	3	1

continued

Table A-3 (continued)

Lead (μg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	12	<5	--	12	<5	--	24	<5	--
Ontonagon	12	<5	--	12	<5	--	24	<5	--
Upper Portage Entry	6	<5	--	6	<5	--	12	<5	--
Lower Portage Entry	6	<5	--	6	<5	--	12	<5	--
Eagle Harbor	6	<5	--	6	<5	--	12	<5	--
Isle Royale	6	<5	--	4	<5	--	10	<5	--
Big Bay	12	<5	--	12	<5	--	24	<5	--
Presque Isle (Marquette)	12	<5	--	12	<5	--	24	<5	--
Carp River (Marquette)	12	<5	--	12	<5	--	24	<5	--
Munising	12	<5	--	12	<5	--	24	<5	--
Grand Marais	12	<5	--	12	<5	--	24	<5	--
Whitefish Point	12	<5	--	12	<5	--	24	<5	--
Lake Huron									
Detour	12	<5	--	12	<5	--	24	<5	--
Cheboygan	12	7	1	12	6	3	24	7	2
Presque Isle	12	4	4	12	6	2	24	5	4
Alpena	12	7	3	12	7	2	24	7	2
Harrisville	12	6	2	12	3	4	24	5	3
Tawas	12	<5	--	12	<5	--	24	<5	--
Saginaw Bay	6	7	3	6	5	3	12	6	3
Harbor Beach	12	6	1	12	7	2	24	7	1
Lexington	12	8	3	12	6	2	24	7	3

Zinc (μg/l)

	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	12	4	5	12	14	21	24	9	16
Ontonagon	12	2	2	12	11	17	24	7	13
Upper Portage Entry	6	2	2	6	5	1	12	4	2
Lower Portage Entry	6	7	8	6	5	2	12	6	6
Eagle Harbor	6	8	12	6	6	4	12	7	9
Isle Royale	6	4	1	4	6	4	10	5	3
Big Bay	12	9	2	12	12	8	24	11	6
Presque Isle (Marquette)	12	8	3	12	12	8	24	10	6
Carp River (Marquette)	12	3	2	12	11	8	24	9	7
Munising	12	11	5	12	9	4	24	10	4
Grand Marais	12	7	9	12	13	8	24	10	9
Whitefish Point	12	7	4	12	9	5	24	8	4
Lake Huron									
Detour	12	10	7	12	29	35	24	20	27
Cheboygan	12	6	1	12	11	7	24	8	6
Presque Isle	12	7	6	12	9	15	24	8	11
Alpena	12	6	5	12	7	2	24	7	4
Harrisville	12	11	8	12	6	2	24	9	6
Tawas	12	14	5	12	5	2	24	10	6
Saginaw Bay	6	23	18	6	10	4	12	16	14
Harbor Beach	12	6	5	12	8	3	24	9	4
Lexington	12	3	3	12	12	5	24	7	6

* Exceeds IJC Water Quality Objective

continued

Table A-3 (continued)

	Chemical Oxygen Demand								
	SPRING			FALL			ANNUAL		
Lake Superior	n	$\bar{X}$	SD	n	$\bar{X}$	SD	n	$\bar{X}$	SD
Black River	4	5.3	1.6	4	4.3	0.3	8	4.8	0.7
Ontonagon	8	4.8	1.0	13	5.9	1.8	21	5.4	0.8
Upper Portage Entry	6	5.4	0.7	6	4.5	0.5	12	5.0	0.7
Lower Portage Entry	5	3.3	0.8	6	7.7	0.1	11	5.5	3.1
Eagle Harbor	1	4.5	0.0	2	5.2	1.1	3	4.9	0.5
Isle Royale	6	5.1	0.4	4	10.6	2.5	10	7.8	3.9
Big Bay	4	4.3	0.9	4	10.0	2.9	8	7.1	4.1
Presque Isle (Marquette)	11	4.4	1.2	12	6.6	1.9	23	5.5	1.5
Carp River (Marquette)	12	2.7	1.0	12	7.9	2.3	24	5.2	3.7
Munising	15	5.4	1.3	12	4.0	1.4	27	4.7	1.0
Grand Marais	4	6.8	3.2	6	7.1	6.2	10	6.9	0.3
Whitefish Point	4	4.6	2.0	4	3.7	0.3	8	4.1	0.7
Lake Huron									
Detour	4	5.5	1.2	4	3.7	0.6	8	4.6	1.3
Cheboygan	12	5.8	1.2	11	5.6	0.9	23	5.7	0.2
Presque Isle	4	5.8	2.2	4	5.4	0.2	8	5.6	0.3
Alpena	12	15.2	7.6	12	7.0	0.3	24	11.1	5.8
Harrisville	-	--	--	4	4.9	0.2	4	4.9	0.2
Tawas	12	6.0	1.3	12	5.3	0.8	24	5.6	0.5
Saginaw Bay	5	12.2	2.6	6	10.7	4.0	11	11.5	1.1
Harbor Beach	12	3.7	1.9	12	6.5	0.8	24	5.1	2.0
Lexington	4	4.5	2.6	4	6.0	1.2	8	5.3	1.1

Table A-4. Combined spring and fall correlation coefficients for selected water constituents in Lake Superior, 1974*

	Dissolved oxygen	Temperature	Chemical oxygen demand	Alkalinity	Hardness	Conductivity	Turbidity	Nitrate
Dissolved oxygen	1.000	0.387			-0.275	-0.175		
Temperature	-0.387	1.000			0.249			
Chemical oxygen demand			1.000					
Alkalinity				1.000	0.880	0.762		
Hardness	-0.275	0.249		0.880	1.000	0.794		
Conductivity	-0.175			0.762	0.794	1.000		
Turbidity							1.000	0.331
Nitrate							-0.331	1.000
Ammonia	-0.181			0.345	0.733	0.298		
Organic nitrogen			0.182	0.259	0.217	0.192	0.326	
Total phosphorus				0.362	0.389	0.147	0.205	
Orthophosphate				0.520	0.353			
Total dissolved solids				0.924	0.935	0.765	0.227	
Suspended solids							0.616	
Reactive silica		-0.389					0.276	-0.181
Chloride	-0.168			0.638	0.380	0.449	0.288	-0.145
Total nitrogen			0.214	0.439	0.207			0.720
Sulfate				0.557	0.649	0.332	0.248	
Calcium				0.619	0.796	0.390		
Magnesium	-0.327	0.357		0.578	0.839	0.435		
Sodium	-0.340	0.290		0.456	0.700	0.296		
Potassium	-0.350	0.377		0.334	0.579	0.302		
Chlorophyll *a*								

* all correlations significant at 0.01

continued

Table A-4 (continued)

	Ammonia	Organic nitrogen	Total phosphorus	Orthophosphate	Total dissolved solids	Suspended solids	Reactive silica	Chlorides
Dissolved oxygen		-0.181						
Temperature							-0.389	0.168
Chemical Oxygen demand			0.182					
Alkalinity	0.345	0.259	0.262	0.520	0.924			0.628
Hardness	0.733	0.215	0.389	0.353	0.935			0.380
Conductivity	0.298	0.192	0.147		0.765			0.449
Turbidity		0.326	0.205		0.227	0.616	0.276	0.288
Nitrate							-0.181	-0.145
Ammonia	1.000	0.246	0.593	0.672	0.516		0.207	0.256
Organic nitrogen	0.246	1.000	0.421	0.474	0.334		0.393	0.221
Total phosphorus	0.593	0.421	1.000	0.968	0.531		0.486	0.487
Orthophosphate	0.672	0.474	0.968	1.000	0.489	0.515	0.584	0.582
Total dissolved solids	0.516	0.334	0.531	0.489	1.000			0.847
Suspended solids				0.515		1.000		
Reactive silica	0.207	0.393	0.486	0.584			1.000	0.256
Chloride	0.256	0.221	0.487	0.582	0.847		0.256	1.000
Total nitrogen	0.166	0.713	0.271	0.296	0.554		0.394	
Sulfate	0.691	0.433	0.729	0.729	0.849		0.569	0.720
Calcium	0.638	0.216	0.603	0.654	0.812	0.363	0.344	0.603
Magnesium	0.691		0.646	0.632	0.839	0.434	0.273	0.751
Sodium	0.601	0.222	0.668	0.670	0.776		0.293	0.719
Potassium	0.532	0.201	0.522	0.509	0.609		0.290	0.543
Chlorophyll a								

* all correlations significant at 0.01

continued

Table A-4 (continued)

	Total nitrogen	Sulfate	Calcium	Magnesium	Sodium	Potassium	Chlorophyll a
Dissolved oxygen				-0.327	-0.340	-0.350	
Temperature				0.357	0.290	0.377	
Chemical oxygen demand	0.214						
Alkalinity	0.439	0.557	0.619	0.578	0.456	0.334	
Hardness	0.207	0.649	0.796	0.839	0.700	0.579	
Conductivity		0.332	0.390	0.435	0.296	0.302	
Turbidity		0.248					
Nitrate	0.720						
Ammonia	0.166	0.691	0.638	0.691	0.601	0.532	
Organic nitrogen	0.713	0.433	0.216		0.222	0.201	
Total phosphorus	0.271	0.729	0.603	0.646	0.668	0.522	
Orthophosphate	0.296	0.729	0.654	0.632	0.670	0.509	
Total dissolved solids	0.554	0.849	0.812	0.839	0.776	0.609	
Suspended solids			0.363	0.434			
Reactive silica	0.394	0.569	0.344	0.273	0.293	0.290	
Chloride		0.720	0.603	0.751	0.719	0.543	
Total nitrogen	1.000	0.566	0.447	0.370	0.389	0.313	
Sulfate	0.566	1.000	0.639	0.699	0.678	0.524	
Calcium	0.447	0.639	1.000	0.741	0.622	0.521	
Magnesium	0.370	0.699	0.741	1.000	0.786	0.639	
Sodium	0.389	0.678	0.622	0.786	1.000	0.664	
Potassium	0.313	0.524	0.521	0.639	0.664	1.000	
Chlorophyll a							1.000

* all correlations significant at 0.01

Table A-5. Combined spring and fall correlation coefficients for selected water constituents in Lake Huron, 1974*

	Dissolved oxygen	Temperature	Chemical oxygen demand	Alkalinity	Hardness	Conductivity	Turbidity	Nitrate
Dissolved oxygen	1.000	-0.479		-0.248	0.360	-0.370	-0.282	
Temperature	-0.479	1.000		0.742	0.351	0.299		-0.182
Chemical oxygen demand			1.000	0.440	0.448	0.439	0.490	0.433
Alkalinity	-0.248	0.242	0.440	1.000	0.850	0.894	0.212	0.695
Hardness	-0.360	0.351	0.448	0.850	1.000	0.904	0.228	0.600
Conductivity	-0.370	0.299	0.439	0.894	0.904	1.000	0.366	0.331
Turbidity	-0.282		0.490	0.212	0.228	0.266	1.000	
Nitrate		-0.182	0.433	-0.695	-0.600	-0.331		1.000
Ammonia	-0.339						0.407	
Organic nitrogen	-0.415		0.493	0.238	0.279	0.188	0.448	
Total phosphorus	-0.289	0.180	0.544	0.398	0.392	0.429	0.598	
Orthophosphate	-0.148		0.327	0.370	0.266	0.313	0.388	
Total dissolved solids	-0.299	0.222	0.597	0.928	0.867	0.942	0.347	-0.645
Suspended solids							0.715	
Reactive silica			0.366	0.666	0.415	0.404		-0.316
Chlorides		0.206	0.233		0.471	0.394	0.260	
Total nitrogen			0.276			0.212	0.425	0.856
Sulfate	-0.320		0.659	0.370	0.428	0.459	0.397	-0.374
Calcium	-0.283		0.539	0.897	0.755	0.849	0.302	-0.572
Magnesium			0.327	0.917	0.885	0.932		-0.656
Sodium	-0.295		0.323	0.367	0.576	0.604	0.263	
Potassium		0.276	0.403		0.401	0.403	0.400	0.274
Chlorophyll a	-0.429	0.470	0.749	0.495	0.583		0.488	

* all correlations significant at 0.01

continued

Table A-5 (continued)

	Ammonia	Organic nitrogen	Total phosphorus	Orthophophate	Total dissolved solids	Suspended solids	Reactive silica	Chloride
Dissolved oxygen	-0.339	-0.415	-0.289	-0.148	-0.299			
Temperature			0.180		0.222			0.206
Chemical oxygen demand		0.493	0.544	0.327	0.597		0.366	0.232
Alkalinity		0.238	0.398	0.370	0.928		0.666	
Hardness		0.279	0.392	0.266	0.867		0.415	0.471
Conductivity		0.188	0.429	0.313	0.942		0.404	0.394
Turbidity	0.407	0.448	0.598	0.388	0.347	0.715		0.260
Nitrate					-0.645		0.316	
Ammonia	1.000	0.265	0.468	0.362				0.151
Organic nitrogen	0.265	1.000	0.576	0.424	0.359		0.254	
Total phosphorus	0.468	0.576	1.000	0.767	0.488	0.146	0.373	0.251
Orthophosphate	0.362	0.424	0.767	1.000	0.351		0.355	
Total dissolved solids		0.359	0.488	0.351	1.000		0.519	0.428
Suspended solids			0.146			1.000		
Reactive silica		0.254	0.373	0.355	0.519		1.000	-0.262
Chlorides	0.151		0.251		0.428		-0.262	1.000
Total nitrogen	0.336	0.378	0.270					
Sulfate		0.477	0.400		0.633			0.289
Calcium		0.343	0.579	0.351	0.922		0.613	
Magnesium			0.311	0.265	0.885		0.506	0.351
Sodium		0.181	0.272		0.567			0.686
Potassium					0.407	0.461		0.693
Chlorophyll a		0.367	0.486		0.609			0.498

* all correlations significant at 0.01

continued

Table A-5 (continued)

	Total nitrogen	Sulfate	Calcium	Magnesium	Sodium	Potassium	Chlorophyll a
Dissolved oxygen		-0.320	-0.283		-0.295		-0.429
Temperature						0.276	0.470
Chemical oxygen demand	0.276	0.659	0.539	0.367	0.323	0.403	0.749
Alkalinity		0.370	0.897	0.917	0.367		0.495
Hardness		0.428	0.755	0.885	0.576	0.401	0.583
Conductivity	0.212	0.459	0.849	0.932	0.604	0.403	
Turbidity	0.425	0.397	0.302		0.263	0.400	0.488
Nitrate	0.856	-0.374	-0.572	-0.656		-0.274	
Ammonia	0.151	0.336					
Organic nitrogen	0.378	0.477	0.343		0.181		0.367
Total phosphorus	0.270	0.400	0.579	0.311	0.212		0.486
Orthophosphate			0.351	0.265			
Total dissolved solids		0.633	0.922	0.885	0.567	0.407	0.609
Suspended solids						0.416	
Reactive silica			0.613	0.506			
Chlorides		0.289		0.351	0.686	0.693	0.498
Total nitrogen	1.000	9,287		-0.272		c	
Sulfate	0.287	1.000	0.506	0.306	0.456	0.508	0.651
Calcium		0.506	1.000	0.797	0.382		0.431
Magnesium	-0.272	0.306	0.797	1.000	0.546	0.311	
Sodium		0.456	0.382	0.546	1.000	0.576	0.418
Potassium		0.508		0.311	0.576	1.000	0.727
Chlorophyll a		0.657	0.431		0.418	0.727	1.000

* all correlations significant at 0.01

Table A-6a. Descriptive statistics for chemical and physical constituents in the nearshore waters of Lakes Huron and Superior, 1975

	TEMPERATURE			DISSOLVED OXYGEN			pH		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Lake Superior									
Black River	3	8.6	4.0	3	11.9	1.2			
Ontonagon	10	9.8	1.5	10	11.2	1.0			
Upper Portage Entry	3	6.5	2.6	3	12.8	0.9			
Lower Portage Entry	3	7.6	0.5	3	12.5	0.1			
Eagle Harbor	-	-	-	-	-	-			
Isle Royale	18	4.5	0.9	18	12.3	0.2	12	7.6	
Big Bay	6	7.5	2.9	6	11.7	0.6			
Presque Isle	10	8.3	3.8	10	12.7	0.8			
Carp River	10	8.3	2.8	10	13.1	0.7	8	7.7	
Marquette Harbor	10	9.6	4.1	10	12.7	0.7	6	7.8	
Munising	10	10.9	4.4	10	12.4	0.8			
Grand Marais	10	11.3	1.4	10	12.6	0.4	8	7.6	
Tahquamanon	3	14.0	0.8	3	11.7	0.2			
Lake Huron									
Detour	10	8.8	1.4	10	12.3	0.7			
Cheboygan	10	12.2	2.4	10	11.0	0.6			
Calcite	10	10.7	0.5	10	11.5	0.6	8	7.9	
Presque Isle	10	10.2	0.5	10	11.8	0.4			
Alpena	14	12.9	2.5	14	11.1	1.1			
Harrisville	10	8.8	1.1	10	13.3	0.4			
Tawas	-	-	-	1	8.7	0			
Saginaw Bay	9	21.2	5.7	9	10.7	2.5			
Harbor Beach	10	10.0	2.6	10	12.6	0.8			
Lexington	10	11.1	2.0	10	13.0	1.0			

	TURBIDITY (J.T.U.)			CHLORIDE (mg/l)			SULFATE (mg/l)		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Lake Superior									
Black River				-	-	-	-	-	-
Ontonagon	-	-	-	8	2	1	8	5	2
Upper Portage Entry	8	9.1	13.6	-	-	-	-	-	-
Lower Portage Entry	-	-	-	-	-	-	-	-	-
Eagle Harbor	-	-	-	8	1	0	8	3	0
Isle Royale	8	0.5	0.0	12	1	0	12	3	1
Big Bay	12	0.5	0.1	-	-	-	-	-	-
Presque Isle	-	-	-	8	1	0	8	4	1
Carp River	8	1.3	0.9	8	2	1	8	3	2
Marquette Harbor	8	0.5	0.3	8	1	0	8	3	1
Munising	8	0.4	0.1	8	1	0	8	3	0
Grand Marais	8	0.9	0.5	8	1	0	8	3	1
Tahquamanon	8	0.1	0.0	-	-	-	-	-	-
	-	-	-						
Lake Huron									
Detour				8	4	1	8	11	1
Cheboygan	8	0.4	0.1	8	6	1	8	14	2
Calcite	8	1.3	0.5	8	6	1	8	14	1
Presque Isle	8	1.1	0.4	8	6	1	8	14	1
Alpena	8	0.9	0.4	12	6	2	12	16	1
Harrisville	12	1.3	0.5	8	6	0	8		1
Tawas	8	0.7	0.1	-	-	-	-	-	-
Saginaw Bay	-	-	-	8	16	12	8	22	6
Harbor Beach	8	2.4	2.4	8	6	0	8	15	1
Lexington	8	1.0	0.4	8	5	0	8	15	1
	8	0.7	0.3						

continued

Table A-6a. (continued)

	CONDUCTIVITY (μmho/cm)			TOTAL DISSOLVED SOLIDS (mg/1)			ALKALNITY (mg/1)		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Lake Superior									
Black River	3	87	2	2	57	1	-	-	-
Ontonagon	10	90	9	8	60	4	8	41	1
Upper Portage Entry	3	88	4	2	57	1	-	-	-
Lower Portage Entry	3	85	1	2	56	0	-	-	-
Eagle Harbor	-	-	-	-	-	-	8	40	1
Isle Royale	18	85	1	12	55	1	12	44	1
Big Bay	6	85	1	2	55	1	-	-	-
Presque Isle	10	85	3	8	56	0	8	40	2
Carp River	10	101	27	6	59	3	8	46	4
Marquette Harbor	10	88	3	8	59	1	8	44	1
Munising	10	88	2	8	59	1	8	41	1
Grand Marais	10	85	1	8	56	1	8	41	1
Tahquamanon	3	85	1	-	-	-	-	-	-
Lake Huron									
Detour	10	137	21	8	85	9	8	59	8.4
Cheboygan	10	222	28	8	152	14	8	100	19.3
Calcite	10	188	10	8	126	5	8	79	3.3
Presque Isle	10	190	5	8	124	3	8	81	.2
Alpena	14	208	14	12	139	5	12	91	7.1
Harrisville	10	183	3	8	119	1	8	72	1.0
Tawas	-	-	-	-	-	-	-	-	-
Saginaw Bay	9	242	57	4	146	26	8	91	11.0
Harbor Beach	10	197	5	8	128	2	8	82	1.3
Lexington	10	190	4	8	126	1	8	81	1.3

	TOTAL ORTHO-PHOSPHATE (mg/1)			TOTAL PHOSPHORUS (mg/1)			SILICON DIOXIDE (mg/1)		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Lake Superior									
Black River	2	0.001	0.001	2	0.004	-	-	-	-
Ontonagon	8	0.006	0.008	8	0.015	0.021	8	2.5	0.8
Upper Portage Entry	2	0.002	0.001	2	0.003	0.001	-	-	-
Lower Portage Entry	2	0.001	0.001	2	0.002	-	-	-	-
Eagle Harbor	8	0.002	0.001	8	0.004	0.002	8	2.1	0.0
Isle Royale	12	0.000	0.000	12	0.003	0.004	12	2.1	0.0
Big Bay	2	0.000	0.000	2	0.005	0.001	-	-	-
Presque Isle	8	0.001	0.001	8	0.004	0.006	8	2.4	0.1
Carp River	6	0.037	0.068	6	0.059	0.109	8	2.4	0.2
Marquette Harbor	8	0.001	0.001	8	0.006	0.003	8	2.0	0.0
Munising	8	0.002	0.003	8	0.005	0.002	8	2.2	0.1
Grand Marais	8	0.001	0.001	8	0.006	0.002	8	2.0	0.0
Tahquamanon	2	0.001	0.001	2	0.002	0.001	-	-	-
Lake Huron									
Detour	8	0.002	0.001	8	0.003	0.001	8	1.3	0.1
Cheboygan	8	0.002	0.001	8	0.005	0.001	8	2.0	1.6
Calcite	8	0.002	0.001	8	0.003	0.001	8	1.3	0.1
Presque Isle	8	0.001	0.001	8	0.005	0.001	8	1.2	0.1
Alpena	12	0.003	0.001	12	0.018	0.009	12	1.1	0.3
Harrisville	8	0.001	0.001	8	0.005	0.001	8	1.0	0.1
Tawas	-	-	-	-	-	-	-	-	-
Saginaw Bay	8	0.004	0.007	8	0.032	0.044	8	0.7	0.4
Harbor Beach	8	0.000	0.001	8	0.008	0.003	8	0.6	0.3
Lexington	8	0.000	0.001	8	0.006	0.003	8	0.8	0.0

continued

Table A-6a. (continued)

	CHLOROPHYLL-a (μg/1)			AMMONIA-NITROGEN (mg/1)			NITRATE-NITROGEN (mg/1)		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Lake Superior									
Black River	-	-	-	2	0.003	0.002	2	0.27	0.03
Ontonagon	4	3.06	0.28	8	0.004	0.003	8	0.26	0.04
Upper Portage Entry	-	-	-	2	0.003	0.001	2	0.31	0.01
Lower Portage Entry	-	-	-	2	0.002	0.001	2	0.30	0.01
Eagle Harbor	4	1.78	0.11	8	0.005	0.002	8	0.30	0.01
Isle Royale	6	1.48	0.27	12	0.001	0.002	12	0.30	0.01
Big Bay	-	-	-	2	0.001	0.001	2	0.27	0.01
Presque Isle	4	2.94	1.02	8	0.002	0.002	8	0.26	0.04
Carp River	4	4.63	1.74	8	0.015	0.021	8	0.26	0.02
Marquette Harbor	4	3.68	0.90	8	0.001	0.002	8	0.26	0.01
Munising	4	2.40	0.71	8	0.002	0.002	8	0.25	0.01
Grand Marais	4	1.60	0.39	8	0.001	0.001	8	0.25	0.01
Tahquamanon	-	-	-	2	0.001	0.001	2	0.22	0.00
Lake Huron									
Detour	4	1.80	0.47	8	0.002	0.001	8	0.27	0.01
Cheboygan	4	6.62	8.48	8	0.005	0.002	8	0.18	0.05
Calcite	4	1.98	0.09	8	0.003	0.001	8	0.24	0.01
Presque Isle	4	1.91	0.24	8	0.003	0.001	8	0.23	0.01
Alpena	6	11.34	5.50	12	0.016	0.011	12	0.18	0.03
Harrisville	4	4.74	1.20	8	0.004	0.001	8	0.24	0.01
Tawas	-	-	-	-	-	-	-	-	-
Saginaw Bay	3	60.50	46.76	8	0.009	0.005	8	0.14	0.11
Harbor Beach	4	4.18	1.17	8	0.005	0.004	8	0.28	0.06
Lexington	4	3.38	0.91	8	0.001	0.001	8	0.26	0.01

	ORGANIC-NITROGEN (mg/1)			TOTAL-NITROGEN (mg/1)			COD (mg/1)		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Lake Superior									
Black River	2	0.09	0.01	2	0.37	0.04	-	-	-
Ontonagon	8	0.14	0.09	8	0.40	0.06	8	7.0	8.0
Upper Portage Entry	2	0.08	0.00	2	0.39	0.00	-	-	-
Lower Portage Entry	2	0.08	0.00	2	0.38	0.01	-	-	-
Eagle Harbor	8	0.08	0.02	8	0.39	0.02	8	2.2	0.6
Isle Royale	12	0.10	0.02	12	0.40	0.02	12	2.6	1.3
Big Bay	2	0.08	0.02	2	0.35	0.00	-	-	-
Presque Isle	8	0.10	0.03	8	0.36	0.04	8	6.8	1.6
Carp River	8	0.17	0.20	8	0.45	0.20	8	3.8	3.3
Marquette Harbor	8	0.11	0.02	8	0.36	0.02	8	1.3	0.7
Munising	8	0.09	0.01	8	0.34	0.02	8	5.9	1.9
Grand Marais	8	0.08	0.01	8	0.33	0.02	8	2.0	0.7
Tahquamanon	2	0.08	0.03	2	0.30	0.03	-	-	-
Lake Huron									
Detour	8	0.11	0.02	8	0.39	0.02	8	4.8	0.6
Cheboygan	8	0.14	0.03	8	0.32	0.02	8	4.5	2.1
Calcite	8	0.12	0.02	8	0.37	0.02	8	3.0	1.2
Presque Isle	8	0.13	0.01	8	0.36	0.02	8	3.1	1.0
Alpena	12	0.25	0.07	12	0.44	0.06	12	10.6	4.5
Harrisville	8	0.17	0.02	8	0.42	0.03	8	3.7	2.2
Tawas	-	-	-	-	-	-	-	-	-
Saginaw Bay	8	0.56	0.51	8	0.71	0.43	8	15.0	10.1
Harbor Beach	8	0.23	0.04	8	0.51	0.07	8	3.9	1.5
Lexington	8	0.19	0.03	8	0.45	0.03	8	3.3	2.1

continued

Table A-6a. (continued)

	ARSENIC (μg/1)			CADMIUM (μg/1)			CHROMIUM (μg/1)		
	N	$\overline{X}$	SD	N	$\overline{X}$	SD	N	$\overline{X}$	SD
Lake Superior									
Black River	3	0.9	0.3	3	0.09	0.07	3	0.5	0.10
Ontonagon	3	0.9	0.1	3	0.15	0.13	3	0.4	0.04
Upper Portage Entry	3	0.8	0.2	3	0.04	0.01	3	0.3	0.00
Lower Portage Entry	3	0.8	0.1	3	0.11	0.02	3	0.3	0.10
Eagle Harbor	3	0.8	0.1	3	0.16	0.00	3	0.3	0.10
Isle Royale	3	0.9	0.2	3	0.04	0.00	3	0.3	0.00
Big Bay	3	0.9	0.2	3	0.23 †	0.13	3	1.3	0.10
Presque Isle	3	0.7	0.1	3	0.05	0.03	3	0.3	-
Carp River	3	0.7	0.0	3	0.06	0.03	3	0.3	-
Marquette Harbor	3	0.7	0.2	3	0.06	0.05	3	0.3	0.10
Munising	3	0.8	0.1	3	0.06	0.04	3	0.5	0.04
Grand Marais	5	0.7	0.1	5	0.48*†	0.31	5	0.4	0.10
Tahquamanon	5	0.8	0.0	5	0.08	0.03	5	0.4	0.10
Lake Huron									
Detour	3	0.8	0.0	3	< 0.04	0.01	3	< 0.3	-
Cheboygan	3	0.9	0.1	3	< 0.03	0.01	3	0.4	0.05
Calcite	3	0.9	0.3	3	< 0.04	0.01	3	0.3	-
Presque Isle	3	0.8	0.1	3	< 0.04	-	3	< 0.3	-
Alpena	3	0.8	0.2	3	0.12	0.16	3	< 0.3	-
Harrisville	3	0.8	0.3	3	0.15	0.04	3	< 0.3	-
Tawas	3	0.9	0.3	3	0.14	0.07	3	0.8	0.90
Saginaw Bay	5	0.8	0.2	5	0.10	0.05	5	0.4	0.04
Harbor Beach	3	0.7	0.1	3	0.10	0.07	3	0.5	0.10
Lexington	3	0.7	0.1	3	0.04	0.01	3	0.4	0.02

† Exceeds EPA criteria
* Exceeds IJC objectives

	COPPER (μg/1)			IRON (μg/1)			MERCURY (μg/1)		
	N	$\overline{X}$	SD	N	$\overline{X}$	SD	N	$\overline{X}$	SD
Lake Superior									
Black River	3	1.7	0.6	3	19	1.7	1	< 0.02	-
Ontonagon	3	1.5	0.9	3	30	7.6	1	< 0.02	-
Upper Portage Entry	3	1.3	0.4	3	43	16.0	1	< 0.02	-
Lower Portage Entry	3	1.9	0.4	3	9	1.1	1	< 0.02	-
Eagle Harbor	3	1.4	0.2	3	49	16.0	1	< 0.02	-
Isle Royale	3	1.0	0.3	3	6	1.4	1	< 0.02	-
Big Bay	3	1.5	0.4	3	8	1.9	1	< 0.02	-
Presque Isle	3	0.9	0.2	3	7	1.0	1	< 0.02	-
Carp River	3	1.3	0.2	3	6	0.8	1	< 0.02	-
Marquette Harbor	3	1.3	0.4	3	6	1.3	1	< 0.02	-
Munising	3	1.7	1.0	3	9	1.4	1	< 0.02	-
Grand Marais	5	2.6	0.8	5	9	1.5	5	< 0.03	0.01
Tahquamanon	5	1.8	0.3	5	10	3.3	5	< 0.04	0.01
Lake Huron									
Detour	3	0.9	0.2	3	21	1.8	1	-	-
Cheboygan	3	1.0	0.5	3	16	1.8	1	< 0.02	-
Calcite	3	2.5	1.3	3	24	6.0	1	< 0.02	-
Presque Isle	3	0.7	0.2	3	24	6.9	1	< 0.02	-
Alpena	3	1.4	0.5	3	11	2.8	1	< 0.02	-
Harrisville	3	3.4	3.2	3	14	2.0	1	< 0.02	-
Tawas	3	2.2	0.1	3	22	5.8	1	-	-
Saginaw Bay	5	1.7	0.4	5	8	1.0	1	< 0.03	0.01
Harbor Beach	3	1.4	0.7	3	23	10.0	1	< 0.04	-
Lexington	3	1.1	0.8	3	18	1.8	1	< 0.02	-

continued

Table A-6a. (continued)

	MANGANESE (μg/1)			NICKEL (μg/1)			LEAD (μg/1)		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Lake Superior									
Black River	3	0.6	0.0	3	0.8	-	3	0.5	0.3
Ontonagon	3	0.6	0.1	3	0.8	-	3	0.4	0.3
Upper Portage Entry	3	0.6	0.1	3	0.9	0.2	3	0.2	0.1
Lower Portage Entry	3	0.6	0.2	3	0.8	-	3	0.3	0.0
Eagle Harbor	3	0.8	0.2	3	0.8	-	3	0.2	0.1
Isle Royale	3	0.3	0.0	3	0.9	-	3	0.2	0.0
Big Bay	3	0.4	0.1	3	0.8	-	3	0.5	0.2
Presque Isle	3	0.3	0.0	3	0.8	-	3	0.3	-
Carp River	3	0.6	0.2	3	0.4	-	3	0.4	0.1
Marquette Harbor	3	0.6	0.2	3	0.8	-	3	0.4	-
Munising	3	0.7	0.1	3	0.8	-	3	0.4	0.2
Grand Marais	5	0.3	0.3	5	0.8	-	5	0.8	0.4
Tahquamanon	5	0.5	0.2	5	0.9	-	5	0.4	0.2
Lake Huron									
Detour	3	1.3	0.1	3	< 0.9	0.1	3	0.4	0.3
Cheboygan	3	1.1	0.1	3	< 0.8	-	3	0.4	0.2
Calcite	3	1.2	0.0	3	< 0.8	-	3	0.4	0.0
Presque Isle	3	1.3	0.1	3	< 0.9	0.1	3	0.4	0.2
Alpena	3	1.3	0.2	3	< 0.8	-	3	0.7	0.4
Harrisville	3	1.0	0.1	3	< 0.9	0.1	3	1.0	0.7
Tawas	3	1.9	0.1	3	0.9	0.1	3	0.8	0.2
Saginaw Bay	5	1.2	0.1	5	1.0	0.1	5	0.5	0.2
Harbor Beach	3	1.5	0.1	3	1.4	0.4	3	0.7	0.1
Lexington	3	1.3	0.3	3	0.9	0.1	3	0.7	0.3

	ZINC (μg/1)		
Lake Superior	N	$\bar{X}$	SD
Lake Superior			
Black River	3	2.3	1.0
Ontonagon	3	1.6	0.6
Upper Portage Entry	3	1.7	1.2
Lower Portage Entry	3	4.4	2.8
Eagle Harbor	3	1.5	0.3
Isle Royale	3	1.5	0.4
Big Bay	3	2.6	1.0
Presque Isle	3	1.1	0.2
Carp River	3	1.0	0.1
Marquette Harbor	3	1.0	0.4
Munising	3	2.1	0.9
Grand Marais	5	2.7	0.9
Tahquamanon	5	2.4	1.3
Lake Huron			
Detour	3	< 2.5	0.4
Cheboygan	3	< 1.9	0.6
Calcite	3	< 2.3	0.8
Presque Isle	3	< 1.6	0.4
Alpena	3	< 3.0	1.3
Harrisville	3	4.9	3.7
Tawas	3	2.4	0.9
Saginaw Bay	5	< 1.3	0.5
Harbor Beach	3	2.5	0.4
Lexington	3	2.2	0.6

Table A-6h. Mean concentrations of heavy metals in unfiltered water samples collected in rivers or very nearshore stations in Lakes Huron and Superior, 1975. All values are expressed in µg/l based on three samples.

	Total Iron	Total Manganese	Total Nickel	Total Copper	Total Zinc	Total Cadmium	Total Lead	Total Mercury	Total Arsenic	Total Chromium
Lake Superior										
Black River	495	29.0	1.1	2.8	3.3	0.20	0.7	<0.02	1.1	0.8
Ontonagon	3487	69.0	5.1	9.1	7.6	0.17	4.0	<0.02	---	---
Upper Portage Entry	88	7.0	<0.8	7.0	<1.6	0.19	0.4	<0.02	0.9	0.6
Lower Portage Entry	148	9.0	<0.8	4.2	<3.0	0.05	<0.2	<0.02	1.0	0.6
Eagle Harbor	42	0.8	<0.8	1.0	<2.0	0.05	<0.2	<0.02	0.8	<0.3
Isle Royale	54	0.3	<0.9	1.0	<1.5	0.02	<0.2	<0.02	0.9	<0.3
Big Bay	12	0.5	<0.8	2.5	<2.7	0.08	<0.3	<0.02	0.9	0.7
Presque Isle	646	61.0	2.3	1.5	6.2	0.14	0.8	<0.02	1.1	1.1
Carp River	524	185.0	2.0	8.2	9.3	0.10	2.2	<0.05	0.9	3.3
Marquette Harbor	32	1.7	<0.8	1.1	<2.5	0.04	<0.4	<0.02	0.9	<0.4
Munising	236	25.0	<0.8	2.5	7.0	0.13	<0.3	<0.02	1.0	<0.1
Grand Marais	39	0.5	<0.8	1.1	5.1	0.05	<0.4	<0.03	0.8	<0.3
Tahquamanon	1496	26.0	-	0.5	3.4	0.04	0.7	<0.04	1.3	<0.3
Lake Huron										
Detour	47	2.3	<0.8	1.2	<2.7	0.03	0.3	---	0.8	<0.3
Cheboygan	93	3.5	<0.8	0.5	<1.0	0.04	0.4	<0.02	0.8	<0.3
Presque Isle	15	1.0	<0.8	1.1	<2.5	<0.04	0.3	<0.03	0.9	<0.3
Thunder Bay River	194	38.0	<0.8	0.8	6.3	0.03	0.6	<0.02	1.0	<0.3
Alpena	37	5.2	<0.8	0.9	2.1	0.04	0.9	<0.02	0.9	<0.3
Harrisville	11	1.0	<0.8	0.9	2.4	0.14	0.3	<0.02	0.8	<0.3
Tawas	400	61.0	4.0	1.1	7.0	0.05	1.4	<0.02	1.4	1.4
Saginaw River	670	76.0	8.0	4.7	17.0	0.13	4.5	<0.04	---	6.5
Harbor Beach	100	4.2	2.0	1.2	<2.6	0.08	0.4	<0.02	0.8	0.6
Lexington	21	1.4	<0.9	1.0	4.0	0.11	0.7	<0.02	0.6	0.7

Table A-7. Descriptive statistics for sediment constituents in the nearshore waters of Lakes Superior and Huron, 1974.

Location	Cases	Volatile Solids (%)* Minimum	Maximum	Mean	Standard Deviation	pH Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Black River	1	0.2	0.2	0.2	---	6.4	6.4	6.4	---
Ontonagon	6	<0.2	2.2	0.8	0.7	7.2	7.9	7.5	0.2
Upper Portage Entry	3	0.2	0.6	0.4	0.2	7.4	7.6	7.5	0.1
Lower Portage Entry	3	0.2	0.2	0.2	0.0	6.1	6.5	6.3	0.2
Eagle Harbor	1	2.6	2.6	2.6	---	7.3	7.3	7.3	---
Isle Royale	2	0.5	0.5	0.5	0.0	7.2	7.3	7.3	0.1
Big Bay	1	0.2	0.2	0.2	---	6.7	6.7	6.7	---
Presque Isle (Marquette)	6	<0.2	0.5	0.3	0.2	6.7	7.5	7.0	0.3
Carp River (Marquette)	6	<0.2	0.4	0.3	0.1	6.5	6.8	6.6	0.1
Munising	6	4.7	32.0	13.0	10.4	5.4	6.7	6.1	0.5
Grand Marais	1	0.5	0.5	0.5	---	7.5	7.5	7.5	---
Whitefish Point	2	0.3	0.4	0.4	0.1	6.2	6.8	6.5	0.4
Lake Huron									
Detour	1	0.2	0.2	0.2	---	7.6	7.6	7.6	---
Cheboygan	5	<0.2	0.7	0.4	0.2	7.1	7.7	7.5	0.2
Presque Isle	1	0.5	0.5	0.5	---	7.5	7.5	7.5	---
Alpena	6	0.3	0.8	0.5	0.2	7.2	7.5	7.4	0.1
Harrisville	1	0.4	0.4	0.4	---	7.2	7.2	7.2	---
Tawas	6	0.2	0.6	0.4	0.1	7.6	8.0	7.8	0.1
Saginaw Bay	3	<0.2	0.3	0.2	0.1	7.4	7.7	7.6	0.2
Harbor Beach	4	0.2	0.9	0.5	0.3	6.8	7.0	6.9	0.1
Lexington	1	0.2	0.2	0.2	---	8.0	8.0	8.0	---

* EPA Criterion: 6%

Location	Cases	Total Kjeldahl Nitrogen (mg/kg)* Minimum	Maximum	Mean	Standard Deviation	Total Solids (%) Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Black River	1	27	27	27	--	87	87	87	--
Ontonagon	6	23	1,200	394	486	70	90	83	7
Upper Portage Entry	3	18	170	71	86	80	85	83	3
Lower Portage Entry	3	81	120	98	20	81	82	81	1
Eagle Harbor	1	80	80	80	--	86	86	86	--
Isle Royale	2	120	340	116	160	60	73	67	9
Big Bay	1	55	55	55	--	81	81	81	--
Presque Isle (Marquette)	6	36	72	54	13	80	89	83	3
Carp River (Marquette)	6	39	130	62	34	81	84	83	1
Munising	6	3,300	4,700	3,766	691	20	38	27	7
Grand Marais	1	14	14	14	--	84	84	84	--
Whitefish Point	2	220	440	330	156	75	81	78	4
Lake Huron									
Detour	1	24	24	24	--	87	87	87	--
Cheboygan	5	82	2,500	356	344	73	86	82	5
Presque Isle	1	120	120	120	--	66	66	66	--
Alpena	6	440	1,700	1,033	469	56	81	72	0
Harrisville	1	80	80	80	--	90	90	90	--
Tawas	6	230	500	330	129	74	84	81	4
Saginaw Bay	3	38	240	110	113	84	91	88	4
Harbor Beach	4	590	4,100	2,573	1,466	43	78	56	15
Lexington	1	360	360	360	--	85	85	85	--

* EPA Criterion: 1,000 mg/kg

Table A-7 (continued)

Location	Cases	---------- Chemical Oxygen Demand------ (mg/kg)* Minimum	Maximum	Mean	Standard Deviation	-- -------Total Phosphorus------------ (mg/kg)* Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Black River	1	900	900	900	----	60	60	60	--
Ontonagon	6	400	85,000	18,950	33,213	71	130	91	21
Upper Portage Entry	3	700	6,500	2,633	3,348	40	130	97	49
Lower Portage Entry	3	1,700	2,200	1,866	288	85	140	112	28
Eagle Harbor	1	900	900	900	----	110	110	110	--
Isle Royale	2	6,000	12,000	9,000	4,242	21	28	25	5
Big Bay	1	2,000	2,000	2,000	----	320	320	320	--
Presque Isle (Marquette)	6	1,200	2,400	1,917	462	56	220	137	60
Carp River (Marquette)	6	700	2,400	1,600	551	110	570	302	154
Munising	6	200,000	660,000	380,000	192,561	150	310	235	62
Grand Marais	1	500	500	500	----	57	57	57	--
Whitefish Point	2	6,200	8,300	7,250	1,484	80	120	100	28
Lake Huron									
Detour	1	500	500	500	----	63	63	63	--
Cheboygan	5	2,600	51,000	27,180	29,711	19	77	56	42
Presque Isle	1	27,000	27,000	27,000	----	55	55	55	--
Alpena	6	9,300	82,000	33,883	26,608	50	160	78	44
Harrisville	1	2,000	2,000	2,000	----	22	22	22	--
Tawas	6	7,900	17,000	11,283	3,757	30	64	49	13
Saginaw Bay	3	1,500	5,200	2,766	2,107	9	38	20	16
Harbor Beach	4	32,000	83,000	62,000	22,315	15	65	50	24
Lexington	1	5,400	5,400	5,400	----	66	66	66	--

* EPA Criterion: 50,000 mg/kg

* EPA Criterion: 420.0 mg/kg

Location	Cases	----------Total Arsenic---------- (mg/kg) * Minimum	Maximum	Mean	Standard Deviation	----------Total Cadmium---------- (mg/kg)* Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Black River	1	0.8	0.8	0.8	----	<0.4	<0.4	<0.4	---
Ontonagon	6	0.4	1.4	0.8	0.4	<0.4	<0.4	<0.4	---
Upper Portage Entry	3	0.5	0.7	0.6	0.1	<0.4	<0.4	<0.4	---
Lower Portage Entry	3	0.7	0.9	0.8	0.1	<0.4	<0.4	<0.4	---
Eagle Harbor	1	0.6	0.6	0.6	----	<0.4	<0.4	<0.4	---
Isle Royale	2	1.2	1.6	1.4	0.3	<0.4	<0.4	<0.4	---
Big Bay	1	1.4	1.4	1.4	----	<0.4	<0.4	<0.4	---
Presque Isle (Marquette)	6	0.5	1.0	0.7	0.2	<0.4	<0.4	<0.4	---
Carp River (Marquette)	6	0.6	1.1	0.7	0.2	<0.4	<0.4	<0.4	---
Munising	6	4.2	9.1	7.3	1.8	<0.4	<0.4	<0.4	---
Grand Marais	1	0.1	0.1	0.1	----	<0.4	<0.4	<0.4	---
Whitefish Point	2	0.8	0.9	0.9	0.1	<0.4	<0.4	<0.4	---
Lake Huron									
Detour	1	2.0	2.0	2.0	---	<0.4	<0.4	<0.4	---
Cheboygan	5	0.5	1.1	1.0	0.4	<0.4	<0.4	<0.4	---
Presque Isle	1	1.2	1.2	1.2	---	<0.4	<0.4	<0.4	---
Alpena	6	1.1	5.5	2.9	1.9	<0.4	<0.4	<0.4	---
Harrisville	1	1.3	1.3	1.3	---	<0.4	<0.4	<0.4	---
Tawas	6	0.7	1.1	0.9	0.1	<0.4	<0.4	<0.4	---
Saginaw Bay	3	1.1	5.6	2.9	2.4	<0.4	<0.4	<0.4	---
Harbor Beach	4	4.4	7.3	5.2	1.4	<0.4	<0.4	<0.4	---
Lexington	1	4.1	4.1	4.1	---	<0.4	<0.4	<0.4	---

* EPA Criterion: 3.0 mg/kg

*EPA Criterion: 6.0 mg/kg

continued

Table A-7 (continued)

Location	Cases	Total Chromium (mg/kg)* Minimum	Maximum	Mean	Standard Deviation	Total Copper (mg/kg)* Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Black River	1	0.4	0.4	0.4	----	2.4	2.4	2.4	----
Ontonagon	6	3.2	11.0	6.1	3.0	5.4	26.0	10.6	8.0
Upper Portage Entry	3	4.8	20.0	10.5	8.3	82.0	280.0	154.0	109.5
Lower Portage Entry	3	1.8	2.4	1.9	0.5	4.6	6.6	5.9	1.1
Eagle Harbor	1	1.4	1.4	1.4	----	34.0	34.0	34.0	----
Isle Royale	2	12.0	12.0	12.0	0.0	15.0	22.0	18.5	4.9
Big Bay	1	2.6	2.6	2.6	----	4.0	4.0	4.0	----
Presque Isle (Marquette)	6	3.8	26.0	9.4	8.4	2.6	19.0	5.9	6.4
Carp River (Marquette)	6	2.0	4.0	3.0	0.0	1.6	3.0	2.0	0.6
Munising	6	2.4	15.0	8.4	5.0	51.0	150.0	96.6	37.1
Grand Marais	1	0.2	0.2	0.2	0.2	1.2	1.2	1.2	----
Whitefish Point	2	<0.2	0.8	0.5	0.0	3.6	10.0	6.8	4.5
Lake Huron									
Detour	1	<0.2	<0.2	<0.2	----	1.2	1.2	1.2	----
Cheboygan	5	2.0	18.0	6.7	6.5	1.0	16.0	4.6	4.0
Presque Isle	1	7.8	7.8	7.8	----	11.0	11.0	11.0	----
Alpena	6	3.0	7.2	5.3	1.7	3.8	12.0	6.5	3.2
Harrisville	1	2.8	2.8	2.8	----	1.8	1.8	1.8	----
Tawas	6	0.6	14.0	7.5	5.1	3.0	12.0	6.9	3.8
Saginaw Bay	3	2.2	7.8	4.3	3.1	1.0	2.8	1.7	1.0
Harbor Beach	4	11.0	19.0	14.2	3.5	14.0	24 0	20.0	4.3
Lexington	1	3.4	3.4	3.4	----	4.6	4.6	4.6	----

* EPA Criterion 25 mg/kg

*EPA criterion: 25 mg/kg

Location	Cases	Total Iron (mg/kg)* Minimum	Maximum	Mean	Standard Deviation	Total Lead (mg/kg)* Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Black River	1	2,000	2,000	2,000	----	3	3	3	----
Ontonagon	6	2,600	6,200	3,380	2,096	<1	8	<1	----
Upper Portage Entry	3	2,800	11,400	6,133	4,614	3	4	4	1
Lower Portage Entry	3	1,400	2,000	1,800	346	<1	1	<1	----
Eagle Harbor	1	3,800	3,800	3,800	----	<1	<1	<1	----
Isle Royale	2	9,600	15,000	12,300	3,818	8	14	11	4
Big Bay	1	4,400	4,400	4,400	----	<1	<1	<1	----
Presque Isle (Marquette)	6	3,000	3,400	4,266	2,053	1	3	2	1
Carp River (Marquette)	6	1,700	3,600	2,466	668	<1	3	1	1
Munising	6	7,300	15,000	12,883	3,013	44	150	80	44
Grand Marais	1	---	---	---	----	3	3	3	
Whitefish Point	2	2,400	4,200	3,300	1,272	3	5	4	1
Lake Huron									
Detour	1	2,600	2,600	2,600	----	<1	<1	<1	- --
Cheboygan	5	2,000	8,600	3,920	2,794	<1	10	5	4
Presque Isle	1	4,800	4,800	4,800	----	19	19	19	----
Alpena	6	3,200	6,000	4,600	1,283	8	30	15	8
Harrisville	1	6,200	6,200	6,200	----	4	4	4	----
Tawas	6	2,200	8,000	5,333	2,477	5	16	10	4
Saginaw Bay	3	1,600	7,800	4,600	3,104	<1	<1	<1	----
Harbor Beach	4	17,000	78,000	34,000	29,720	12	36	27	11
Lexington	1	5,200	5,200	5,200	----	13	13	13	----

* EPA Criterion 17,000 mg/kg

* EPA Criterion: 50 mg/kg

continued

Table A-7 (continued)

Location	Cases	Total Manganese (mg/kg)*				Total Mercury (mg/kg)*			
		Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Black River	1	56	56	56	--	<0.1	<0.1	<0.1	---
Ontonagon	6	48	160	87	44	<0.1	<0.1	<0.1	---
Upper Portage Entry	3	50	240	125	101	<0.1	<0.1	<0.1	---
Lower Portage Entry	3	24	36	31	6	<0.1	<0.1	<0.1	---
Eagle Harbor	1	82	82	82	--	<0.1	<0.1	<0.1	---
Isle Royale	2	300	640	470	240	<0.1	<0.1	<0.1	---
Big Bay	1	64	64	64	--	<0.1	<0.1	<0.1	---
Presque Isle (Marquette)	6	48	310	108	99	<0.1	<0.1	<0.1	---
Carp River (Marquette)	6	36	76	54	16	<0.1	<0.1	<0.1	---
Munising	6	100	220	172	40	0.2	0.5	0.3	0.1
Grand Marais	1	17	17	17	--	<0.1	<0.1	<0.1	---
Whitefish Point	2	28	58	43	21	<0.1	<0.1	<0.1	---
Lake Huron									
Detour	1	130	130	130	----	<0.1	<0.1	<0.1	---
Cheboygan	5	17	110	53	36	<0.1	<0.1	<0.1	---
Presque Isle	1	120	120	120	----	<0.1	<0.1	<0.1	---
Alpena	6	42	110	70	23	<0.1	<0.1	<0.1	---
Harrisville	1	38	38	38	----	<0.1	<0.1	<0.1	---
Tawas	6	42	240	121	76	<0.1	<0.1	<0.1	---
Saginaw Bay	3	20	100	63	40	<0.1	<0.1	<0.1	---
Harbor Beach	4	190	280	243	45	<0.1	0.1	<0.1	---
Lexington	1	110	110	110	----	<0.1	<0.1	<0.1	---

* EPA Criterion: 300.0 mg/kg

Location	Cases	Total Nickel (mg/kg)*				Total Selenium (mg/kg)			
		Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Black River	1	4	4	4	--	<0.1	<0.1	<0.1	----
Ontonagon	6	5	20	10	6	<0.1	<0.1	<0.1	----
Upper Portage Entry	3	10	38	20	15	<0.1	<0.1	<0.1	----
Lower Portage Entry	3	2	2	2	0	<0.1	<0.1	<0.1	----
Eagle Harbor	1	13	13	13	--	<0.1	<0.1	<0.1	----
Isle Royale	2	38	78	58	28	<0.1	<0.1	<0.1	----
Big Bay	1	3	3	3	--	<0.1	<0.1	<0.1	----
Presque Isle (Marquette)	6	6	140	36	52	<0.1	<0.1	<0.1	----
Carp River (Marquette)	6	<1	5	1	2	<0.1	<0.1	<0.1	----
Munising	6	16	38	28	9	<0.1	<0.1	<0.1	----
Grand Marais	1	2	2	2	--	<0.1	<0.1	<0.1	----
Whitefish Point	2	4	6	5	1	<0.1	<0.1	<0.1	----
Lake Huron									
Detour	1	2	2	2	--	<0.1	<0.1	<0.1	----
Cheboygan	5	<1	12	5	4	<0.1	<0.1	<0.1	----
Presque Isle	1	20	20	20	--	<0.1	<0.1	<0.1	----
Alpena	6	6	15	10	3	<0.1	<0.1	<0.1	----
Harrisville	1	5	5	5	--	<0.1	<0.1	<0.1	----
Tawas	6	7	20	13	6	<0.1	<0.1	<0.1	----
Saginaw Bay	3	2	8	6	3	<0.1	<0.1	<0.1	----
Harbor Beach	4	24	38	31	6	<0.1	<0.1	<0.1	----
Lexington	1	10	10	10	--	<0.1	<0.1	<0.1	----

* EPA Criterion 20.0 mg/kg

continued

Table A-7 (continued)

Location	Total Zinc (mg/kg)* Cases	Minimum	Maximum	Mean	Standard Deviation	Oils and Grease (mg/kg)* Cases	Minimum	Maximum	Mean	Standard Deviation
Lake Superior										
Black River	1	8.8	8.8	8.8	---	1	310	310	310	---
Ontonagon	6	6.4	22.0	13.0	6.2	3	230	540	370	157.2
Upper Portage Entry	3	10.0	30.0	19.0	10.1	2	5400	5400	5400	0.0
Lower Portage Entry	3	6.8	9.0	8.1	1.2	2	<35	<35	<35	0.0
Eagle Harbor	1	14.0	14.0	14.0	---	1	300	300	300	---
Isle Royale	2	44.0	84.0	64.0	28.2	2	95	460	278	258.1
Big Bay	1	22.0	22.0	22.0	---	2	<35	70	44	36.8
Presque Isle (Marquette)	6	10.0	48.0	21.8	13.9	3	<35	940	325	532.3
Carp River (Marquette)	6	6.6	17.0	11.1	3.4	3	<35	90	91	88.9
Munising	6	87.0	190.0	134.0	42.5	5	1500	61,000	16,840	24,867.3
Grand Marais	1	16.0	16.0	16.0	---	-	---	---	---	---
Whitefish Point	2	14.0	19.0	16.5	3.5	3	290	6000	3997	3213.6
Lake Huron										
Detour	1	5.4	5.4	5.4	---	1	350	350	350	---
Cheboygan	5	5.6	140.0	40.7	55.8	3	250	3900	1817	1879.1
Presque Isle	1	34.0	34	34.0	---	1	430	430	430	---
Alpena	6	24.0	44	31.0	7.3	3	440	2000	1180	783.1
Harrisville	1	26.0	26	26.0	---	1	240	240	240	---
Tawas	6	12.0	26	19.6	5.5	3	210	400	330	104.4
Saginaw Bay	3	3.4	12	8.3	4.4	4	140	230	195	40.4
Harbor Beach	4	44.0	170	126.0	57.2	2	1300	1400	1350	70.7
Lexington	1	70.0	70	70.0	---	1	330	330	330	---

*EPA Criterion 90 mg/kg

*EPA Criterion 1000 mg/kg

Location	Diethyhexelphthalate (µg/kg) Cases	Minimum	Maximum	$\bar{X}$	SD	Dibutylphthalate (µg/kg) Cases	Minimum	Maximum	$\bar{X}$	SD
Lake Superior										
Black River	1	<90	<90	<90	-	1	100	100	100	0
Ontonagon	3	300	500	396	100	3	110	220	163	55
Upper Portage Entry	2	<90	310	178	187	2	210	260	235	35
Lower Portage Entry	2	330	370	350	28	2	110	120	115	7
Eagle Harbor	1	390	390	390	-	1	280	280	280	0
Isle Royale	2	<90	<90	<90	-	2	<60	<60	<60	-
Big Bay	2	230	600	315	120	2	<60	150	105	64
Presque Isle (Marquette)	3	<90	390	272	196	3	<60	160	103	67
Carp River (Marquette)	3	250	350	290	53	3	<35	190	92	88
Munising	5	270	17,000	4994	6855	5	<60	540	330	274
Grand Marais										
Whitefish Point	3	240	370	316	68	11	260	330	287	38
Lake Huron										
Detour	1	350	350	350	-	1	150	150	150	-
Cheboygan	3	<90	290	126	141	2	350	390	370	28
Presque Isle	1	<90	<90	<90	-	1	260	260	260	-
Alpena	3	<90	350	147	176	3	<200	210	137	64
Harrisville	1	<90	<90	<90	-	1	180	180	180	-
Tawas	3	<90	<90	<90	0		<60	370	143	196
Saginaw Bay	4	<90	<90	<90	0	4	<200	290	173	91
Harbor Beach	2	<90	<90	<90	0	2	<60	<60	<60	0
Lexington	1	410	410	410	0	1	520	520	520	-

continued

Table A-7 (continued)

U.S. EPA guidelines for the pollutional classification of Great Lakes Harbor sediments, 1977.

PARAMETERS	Non Polluted	Moderately Polluted	Heavily Polluted
Volatile Solids (%)	<5	5-8	>8
Oil and Grease	<1,000	1,000-2,000	>2,000
COD	<40,000	40,000-80,000	>80,000
Total Phosphorus	<420	420-650	>650
Ammonia	<75	75-200	>200
TKN	<1,000	1,000-2,000	>2,000
Cyanide	<0.10	0.10-0.25	>0.25
Iron	<17,000	17,000-25,000	>25,000
Manganese	<300	300-500	>500
Barium	<20	20-60	>60
Lead	<40	40-60	>60
Mercury	<1.0	N.A.	>1.0
Nickel	<20	20-50	>50
Arsenic	<3	3-8	>8
Cadmium	*	*	>6
Chromium	<25	25-75	>75
Copper	<25	25-50	>50
Zinc	<90	90-200	>200

* Lower limits not established

Table A-8. Descriptive statistics for sediment constituents in the nearshore waters of Lakes Superior and Huron, 1975.

		Nitrate (mg/kg)				Total Kjeldahl Nitrogen (mg/kg)*			
Location	Cases	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Marquette Harbor	4	0.5	0.7	0.7	0.1	58	280	156	107
Lake Huron									
Calcite	4	0.2	0.6	0.3	0.2	78	710	465	271
Saginaw Bay †	2	0.7	1.3	1.0	0.4	80	130	105	85

* EPA Criterion: 1000 mg/kg

		Total Phosphorus (mg/kg)*				Ammonia (mg/kg)*			
Location	Cases	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Marquette Harbor	4	32	62	47	15	0.2	1.1	1.0	0.8
Lake Huron									
Calcite	4	8	23	16	6	0.2	15.0	5.9	6.2
Saginaw Bay †	2	21	29	25	6	0.4	0.4	0.4	0.0

* EPA Criterion: 420 mg/kg

* EPA Criterion: 75 mg/kg

		Total Solids (%)				Volatile Solids (%)*			
Location	Cases	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Marquette Harbor	4	80	85	83	2	0.4	0.4	0.4	0
Lake Huron									
Calcite	4	64	91	72	13	0.2	0.5	0.3	0.2
Saginaw Bay †	2	83	83	83	0.0	0.4	0.4	0.4	0.0

* EPA Criterion: 5% dry weight

† Saginaw Bay data was calculated without river stations

Table A-8 (continued)

Location	Cases	Chemical Oxygen Demand (mg/kg)*				Total Arsenic (mg/kg)*			
		Minimum	Maximum	Mean	Standard Deviation	Minumum	Maximum	Mean	Standard Deviation
Lake Superior									
Marquette Harbor	4	920	8800	4880	4358	0.5	1.0	0.7	0.3
Lake Huron									
Calcite	4	1300	30,000	2500	949	0.4	1.8	0.9	0.6
Saginaw Bay †	2	1300	2,800	2050	1060	0.8	1.8	1.3	0.7

* EPA Criterion: 50,000 mg/kg

*EPA Criterion: 3.0 mg/kg

Location	Cases	Total Cadmium (mg/kg)*				Total Chromium (mg/kg)*			
		Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Marquette Harbor	4	0.2	0.2	0.2	0	2.0	4.0	3.1	0.8
Lake Huron									
Calcite	4	0.2	0.2	0.2	0	3.4	26.0	16.1	9.4
Saginaw Bay †	2	0.4	0.4	0.4	0.0	2.0	2.6	2.3	0.4

* EPA Criterion: 6.0 mg/kg

* EPA Criterion: 25.0 mg/kg

Location	Cases	Total Copper (mg/kg)*				Total Iron (mg/kg)*			
		Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Marquette Harbor	4	2.2	5.2	3.3	1.4	2000	2800	2200	516.4
Lake Huron									
Calcite	4	0.6	6.0	4.0	2.5	1700	3800	2500	948.7
Saginaw Bay †	2	0.2	0.4	0.3	0.1	1600	2600	2100	707

* EPA Criterion: 25 mg/kg

* EPA Criterion: 17,000 mg/kg

† Saginaw Bay data was calculated without river stations

continued

Table A-8 (continued)

Location	Cases	Total Lead (mg/kg)*				Total Manganese (mg/kg)*			
		Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Marquette Harbor	4	2.0	8	4.5	2.7	24	70	53	22
Lake Huron									
Calcite	4	4.0	12	8.8	3.6	56	88	74	13
Saginaw Bay †	2	0.5	2	1.3	1.1	19	36	28	12

* EPA Criterion: 40.0 mg/kg

* EPA Criterion: 300.0 mg/kg

Location	Cases	Total Mercury (mg/kg)*				Total Nickel (mg/kg)*			
		Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Marquette Harbor	4	0.01	0.04	0.02	0.02	2	7	3.8	2.4
Lake Huron									
Calcite	4	0.01	0.07	0.05	0.03	2	7	5.5	2.4
Saginaw Bay †	2	0.02	0.02	0.02	0.00	3	3	0.0	

* EPA Criterion: 1.0 mg/kg

* EPA Criterion: 20.0 mg/kg

Location	Cases	Total Selenium (mg/kg)				Total Zinc (mg/kg)*			
		Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation
Lake Superior									
Marquette Harbor	4	0.1	0.1	0.1	0	7.0	17.0	11.5	4.1
Lake Huron									
Calcite	4	0.1	0.2	0.4	0.4	9.4	26.0	19.4	7.1
Saginaw Bay †	2	<0.1	<0.1	<0.1	0.0	6.0	10.0	8.0	2.8

* EPA Criterion: 90.0 mg/kg

† Saginaw Bay data was calculated without river stations

Table A-9. List of phytoplankton species found in nearshore Lake Superior, spring and fall, 1974.

- Chlorophyta
  - Ankistrodesmus convolutus
  - A. falcatus
  - A. spiralis
  - Cerasterias irregularis
  - Chlamydomonas globosa
  - C. polypyrenoideum
  - C. snowii
  - C. sp
  - C. sp 1
  - C. sp 2
  - Chlorella ellipsoidea
  - Closteriopsis longissima
  - Closterium gracile
  - C. parvulum
  - Coelastrum dubium
  - C. kuetzingianum
  - C. microporum
  - C. reticulatum
  - C. sphaericum
  - Cosmarium contractum
  - C. formulosum
  - C. psuedoprotuberans
  - C. subtumidum
  - C. sp.
  - Crucigenia apiculata
  - C. quadrata
  - C. tetrapedia
  - Dactylococcus infusionum
  - D. sp.
  - Dictyosphaerium ehrenbergianum
  - D. pulchellum
  - Dispora crucigenioides
  - Elakatothrix gelatinosa
  - E. viridis
  - E. sp.
  - Franceia droescheri
  - F. ovalis
  - Gloecystis ampla
  - G. gigas
  - G. major
  - G. sp.
  - Golenkinia paucispina
  - G. radiata
  - G. sp.
  - Hyalotheca mucosa
  - Kirchneriella contorta
  - K. lunaris
  - K. obesa
  - Lagerheimia ciliata
  - L. citriformis
  - L. longiseta
  - L. subsalsa
  - L. sp.
  - Micractinium pusillum
  - Mougeotia americana
  - M. elegantula
  - M. sp.
  - Oocystis borgei
  - O. elliptica
  - O. pusilla
  - O. submarina
  - Pediastrum biradiatum
  - P. boryanum
  - P. duplex
  - P. duplex var. gracilimum
  - P. tetras
  - Penium sp.
  - Scenedesmus abundans
  - S. acuminatus
  - S. acutiformis
  - S. armatus
  - S. bijuga
  - S. dimorphus
  - S. longus
  - S. obliquus
  - S. opoliensis
  - S. quadricauda
  - Schroederia setigera
  - Sphaerocystis schoeteri
  - Staurastrum chaetocercus
  - S. dejectum
  - S. furcigerum
  - S. paradoxum
  - S. polymorphum
  - S. sebaldi
  - Stipitococcus vasiformis
  - S. sp.
  - Tetraedron arthrodesmiforme
  - T. caudatum
  - T. minimum
  - T. pentaedricum
  - T. prescottii
  - T. trigonum
  - T. sp.
  - Tetrastrum glabrum
  - T. heteracanthum
  - T. regulare
  - Ulothrix subconstricta
  - U. subtilissima
  - U. sp.
  - Unknown Chlorophyta

- Bacillariophyta
  - Achnanthes affinis
  - A. clevei
  - A. flexella
  - A. hungarica
  - A. lanceolata
  - A. minutissima
  - A. sp.
  - Amphora ovalis
  - A. ovalis var. lybica
  - A. perpusilla
  - A. sp.
  - Amphipleura pellucida

continued

Table A-9 (continued)

Amphiprora ornata
Anomoeneis vitrea
Astrionella formosa
A. gracillima
Attheya zachariasi
Cocconeis diminuta
C. pediculus
C. placentula
C. sp.
Coscinodiscus rothii
Cyclotella antiqua
C. atomus
C. caspia
C. comensis
C. comta
C. glomerata
C. kutzingiana
C. meneghiniana
C. michiganiana
C. ocellata
C. pseudostelligera
C. stelligera
C. striata
C. sp.
C. sp. 1
Cymatopleura solea
Cymbella affinis
C. cesatii
C. cuspidata
C. inaequalis
C. mirocephala
C. postata
C. sinuata
C. tumida
C. tumidula
C. turgida
C. ventricosa
C. sp.
Denticula elegans
D. tenuis
Diatoma elongatum
D. tenue
D. vulgare
Diploneis elliptica
D. marginestriata
D. oculata
D. puella
Epithemia sp.
Eunotia pectinalis
Fragilaria capucina
F. construens
F. crotonensis
F. gracile
F. harrissonii
F. intermedia
F. lapponica
F. leptostauron
F. pinnata
F. vaucheriae
F. sp.
Gomphonema angustatum
G. olivaceum
G. sp.
Gyrosigma sp.
Melosira granulata
M. islandica
M. varians
Meridion circulare
Navicula cryptocephala
N. cryptocephala var. veneta
N. decussis
N. elginensis
N. exigua
N. gregaria
N. hustedii
N. lanceolata
N. menisculus
N. placentula
N. pupula
N. radiosa
N. reinhardtii
N. subtilissima
N. tripunctata
N. tuscula
N. viridula
Neidium affine
N. iridis
Nitzschia acicularis
N. bacata
N. filiformis
N. fonticola
N. gracilis
N. kutzingiana
N. linearis
N. palea
N. sinuata
Opephora martyi
Rhizosolenia eriensis
R. longiseta
Rhoicosphenia curvata
Stephanodiscus astraea
S. astraea var. minutula
S. dubius
S. hantzschii
S. invisitatus
Surirella ovalis
S. ovata
S. robusta
S. sp.
Synedra acus
S. amphicephala
S. cyclopum
S. delictissima
S. radians
S. rumpens
S. tenera
S. ulna
S. vaucheriae
S. sp.
Tabellaria fenestrata
T. flocculosa
Unknown Bacillariophyta

Cyanophyta
Anabaena felissii
A. flos-aquae
A. planctonica
A. subcylindrica
A. wisconsinense
A. sp.
Aphanocapsa delicatissima
A. elachista
Aphanothece clathrata
A. microspora
A. nidulans
A. sp.
Chamaesiphon confervicola
Chroococcus dispersus
C. kuetzingianum
C. limneticus
C. microspora
C. minor
C. minutus

(continued)

Table A-9 (continued)

- *C. prescottii*
- *Coelosphaericum naegelianum*
- *Cyanarcus hamiformis*
- *Dactylococcopsis acicularis*
- *D. fascicularis*
- *D. smithii*
- *D. sp.*
- *Gomphosphaeria aponina*
- *G. lacustris*
- *Lyngbya contorta*
- *Merismopedia convoluta*
- *M. punctata*
- *Microcystis aeruginosa*
- *M. flos-aquae*
- *M. incerta*
- *Oscillatoria acutissima*
- *O. angusta*
- *O. angustissima*
- *O. prolifica*
- *O. splendida*
- *O. subbrevis*
- *O. tenuis*
- *O. sp.*
- *Phormidium mucicola*
- *P. tenue*
- Unknown blue-green

Chrysophyta
- *Chrysosphaerella longispina*
- *Dinobryon bavaricum*
- *D. caudata*
- *D. divergens*
- *D. sertularia*
- *D. sociale*
- *D. stipitatum*
- *D. tabellariae*
- *Mallomonas acaroides*
- *M. alpina*
- *M. caudata*
- *Ophiocytium capitatum*
- *Stipitococcus vasiformis*
- *Synura ulvella*
- *S. sp.*

Cryptophyta
- *Chroomonas nordstedtii*
- *Cryptomonas erosa*
- *C. ovata*
- *C. sp.*
- *Rhodomonas minuta*

Pyrrophyta
- *Ceratium hirundinella*

Euglenophyta
- *Euglena sp.*
- *Phacus sp.*

Chloromonadophyta
- *Gonyostomum semen*
- Unknown flagellates

Table A-10. Abundance of phytoplankton by class in nearshore Lake Superior, 1974.

Location (#)	Month	Sample type	Number of samples	Mean Phytoplankton unit/ml	Mean Chlorophyta unit/ml	Mean Bacillariophyta unit/ml	Mean Cyanophyta unit/ml	Mean Chrysophyta unit/ml
Black River (1)	July	g	3	2,136	66	1,278	60	125
		c	3	1,913	139	1,130	14	52
	Sept	g	3	1,548	144	533	145	302
		c	3	2,111	198	1,102	147	316
Ontonagon (2)	July	g	2	2,104	49	1,069	14	48
		c	3	1,208	249	710	11	61
	Sept	g	3	1,202	112	279	144	441
		c	3	1,701	172	569	245	331
Upper Portage Entry (3)	July	g	2	1,772	174	744	86	58
		c	3	2,068	276	1,228	127	131
	Sept	g	2	1,513	164	365	312	310
		c	2	1,918	218	395	347	416
Lower Portage Entry (4)	July	g	2	1,336	113	1,036	178	3
		c	2	1,781	202	1,373	188	
	Sept	g	2	1,362	106	453	26	264
		c	2	1,724	196	418	198	255
Eagle Harbor (5)	July	g	2	1,693	318	784	220	32
		c	2	2,539	278	1,231	574	136
	Sept	g	2	2,710	336	1,001	349	556
		c	2	1,632	183	732	190	180
Isle Royale (6)	July	g	2	359	44	227	82	4
		c	2	328	40	200	82	4
	Sept	g	2	1,486	149	553	86	615
		c	2	2,593	269	900	302	816
Big Bay (7)	July	g	3	1,583	266	824	117	23
		c	3	1,221	219	568	48	32
	Sept	g	3	1,136	217	297	173	197
		c	2	1,120	156	320	176	210
Marquette (8)	July	g	3	1,346	116	789	181	90
		c	3	2,498	607	1,158	227	24
	Sept	g	2	1,318	160	266	90	306
		c	3	1,091	90	444	38	189
Munising (9)	July	g	3	1,834	187	902	326	173
		c	3	2,075	196	1,103	131	45
	Sept	g	3	1,922	226	679	430	173
		c	3	1,833	90	678	157	86

Table A-10 (continued)

Location (#)	Month	Sample type	Number of samples	Mean Phytoplankton unit/ml	Mean Chlorophyta unit/ml	Mean Bacillariophyta unit/ml	Mean Cyanophyta unit/ml	Mean Chrysophyta unit/ml
Grand Marais (10)	July	g	3	1,723	165	717	510	41
		c	3	1,035	175	1,241	125	72
	Sept	g	3	1,287	189	494	358	112
		c	3	1,637	251	595	340	192
Whitefish Point (11)	July	g	3	1,612	147	815	198	107
		c	3	1,528	181	769	164	69
	Sept	g	3	585	98	170	153	85
		c	2	968	107	360	252	143
Carp River (21) (Marquette)	July	g	3	2,698	302	1,565	280	145
		c	2	1,415	208	890	125	66
	Sept	g	2	1,454	270	408	160	224
		c	3	2,256	195	594	84	234

g = grab sample
c = composite sample

continued

Table A-10 (continued)

Location (#)	Month	Sample type	Number of samples	Mean Cryptophyta unit/ml	Mean Pyrrophyta unit/ml	Mean Euglenophyta unit/ml	Mean Chloromonadophyta unit/ml	Mean Unknown unit/ml
Black River (1)	July	g	3	606				
		c	3	573		2	3	
	Sept	g	3	406				
		c	3	310	1			37
Ontonagon (2)	July	g	2	924				
		c	3	171			5	
	Sept	g	3	226			1	
		c	3	404				
Upper Portage Entry (3)	July	g	2	548			13	149
		c	3	203				103
	Sept	g	2	362				
		c	2	542				
Lower Portage Entry (4)	July	g	2	8				
		c	2	8				
	Sept	g	2	513				
		c	2	657				
Eagle Harbor (5)	July	g	2	258				81
		c	2	226				94
	Sept	g	2	468				
		c	2	348				
Isle Royale (6)	July	g	2	2				
		c	2	1				
	Sept	g	2	82				
		c	2	306				
Big Bay (7)	July	g	3	314				39
		c	3	354				
	Sept	g	3	252				
		c	2	258				
Marquette (8)	July	g	3	166				4
		c	3	341		5		135
	Sept	g	2	496				
		c	3	329				
Munising (9)	July	g	3	518				
		c	3	601				
	Sept	g	3	518				
		c	3	355				

g - grab sample
c = composite sample

continued

Table A-10 (continued)

Location (#)	Month	Sample type	Number of samples	Mean Cryptophyta unit/ml	Mean Pyrrophyta unit/ml	Mean Euglenophyta unit/ml	Mean Chloromonadophyta unit/ml	Mean Unknown unit/ml
Grand Marais (10)	July	g	3	69				
		c	3	110				
	Sept	g	3	126				7
		c	3	259				
Whitefish Point (11)	July	g	3	296				48
		c	3	329				17
	Sept	g	3	64				16
		c	2	105	1			
Carp River (21) (Marquette)	July	g	3	396				
		c	2	103				24
	Sept	g	2	391				
		c	3	456				

g = grab sample
c = composite sample

Table A-11. Zooplankton species presence in nearshore Lake Superior, spring and fall, 1974.

Location:	1		2		3		4		5		6		7		8		9		10		11		12	
Species	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F
Rotatoria																								
Conchilidae																								
Conchilus unicornus	X			X			X		X	X		X		X	X	X	X	X	X	X	X		X	
Filinidae																								
Filinia longiseta	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Synchaetidae																								
Polyarthra vulgaris	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gastropidae																								
Gostropus stylifer												X				X		X						
Asplanchnidae																								
Asplanchna priodonta	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Brachionidae																								
Brachionus calcyiflorus	X	X			X	X	X	X		X	X	X	X	X	X	X		X		X	X	X	X	
Kellicottia longispina	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Keratella cochlearis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cladocera																								
Leptodoridae																								
Leptodora kindtii		X																	X	X				
Polyphemoidae																								
Polyphemus pediculus																		X		X				
Holopedidae																								
Holopedium gibberum	X	X	X	X		X								X		X		X	X	X	X	X		X
Daphnidae																								
Daphnia longiremus	X		X								X		X						X				X	
D. galeata mendotae			X	X			X	X				X		X		X	X			X				X
D. retrocurua		X		X		X	X	X				X	X	X		X		X	X	X		X		X
Bosminidae																								
Bosmina longirostris	X	X	X	X			X	X		X			X	X	X	X	X	X	X	X	X		X	X
Bosmina coregoni									X	X				X										
Copepoda																								
Calanoida																								
Pseudocalanidae																								
Senecella calanoides											X	X					X						X	
Centropagidae																								
Limnocalnus macrurus		X			X				X	X			X	X		X			X		X	X		X
Temoridae																								
Epischura lacustris	X	X	X	X		X	X	X		X				X	X	X		X	X	X		X		X
Diaptomidae																								
Diaptomus ashlandi	X								X		X										X		X	
D. minutis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. oregonensis	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
D. sicilis	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X		X	X	X	X
Cyclopoida																								
Tropocyclops praisinus														X										
Cyclops bicuspidatus thomasi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nauplii	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mysidacea																								
Mysidae																								
Mysis relicta								X								X			X					

Table A-12. Abundance of zooplankton by major taxonomic group in Lake Superior, 1974.

Location (# of Stations)	Ratio of Calanoids to Cyclopoids + Cladacerans		Mean total # Organisms/m³		Mean # Rototoria/m³		Mean # Cladocera/m³		Mean # Calanoida/m³		Mean # Cyclopoida/m³		Mean # Nauplii/m³		Mean # Mysidae/m³	
	S*	F*	S*	F*	S*	F*	S*	F*	S*	F*	S*	F*	S*	F*	S*	F*
Background																
Black River (3)	2.66	1.20	2254	2640	1111	1098	35	246	401	514	134	280	573	502	-	-
Eagle Harbor (2)	9.41	0.93	2588	1533	1715	645	6	61	315	270	31	251	521	306	-	-
Isle Royale (2)	2.81	2.07	1303	1576	451	401	2	22	244	397	86	181	520	575	-	-
Big Bay (3)	2.75	0.23	1933	4061	572	2619	48	360	270	169	85	510	958	403	-	-
Grand Marais (3)	1.90	0.50	7877	2298	1343	972	221	105	2944	241	1399	428	1970	552	-	-
Whitefish Point (3)	2.34	0.54	4880	2022	1280	971	189	151	1393	233	409	335	1609	332	-	-
Impacted																
Ontonagon (3)	1.90	0.58	5970	3671	2766	1510	65	474	777	485	389	554	1973	648	-	-
Lower Portage Entry (2)	0.45	0.41	6335	4453	2843	1611	460	516	617	475	1105	860	1310	985	-	2
Presque Isle (3)	2.72	0.58	4043	5742	1988	4259	47	438	458	282	155	267	1395	496	-	-
Carp River (3)	2.98	0.73	6817	10,225	5201	2351	28	2544	587	2070	182	1258	819	2002	-	-
Munising (3)	2.26	0.57	5082	2741	1584	1580	221	115	1237	228	432	339	1606	479	2	-
Upper Portage Entry (2)	2.34	0.50	4188	1833	2258	649	0	321	404	225	172	269	1354	369	-	-

* S = Spring
F = Fall

Table A-13. Macroinvertebrate presence in nearshore Lake Superior at Black River (1), Ontonagon (2), Upper Portage Entry (3), Lower Portage Entry (4), Eagle Harbor (5), Isle Royale (6), Big Bay (7), Marquette (Presque Isle) (8), Munising (9), Grand Marais (10), Whitefish Point (11) and Marquette (Carp River) (21), during 1974 and Munising Harbor and Marquette Harbor in 1975

	Location													
Taxa	1	2	3	4	5	6	7	8	9	10	11	21	Munising	Marquette
Platyhelminthes														
Tricladida		X		X			X	X	X		X	X		
Nematoda		X		X	X			X	X		X	X		X
Annelida														
Oligochaeta														
Enchytraeidae	X				X	X	X	X			X	X		X
Lumbriculidae														
Lumbriculus variegatus														
Stylodrilus heringianus	X	X		X		X	X	X	X		X	X	X	X
Naididae														
Amphichaeta leydigii		X												
Arcteonais lomondi		X		X			X	X	X	X	X	X		X
Dero digitata									X					
Nais sp.		X	X	X				X	X	X	X	X		X
N. barbata								X	X	X	X	X		
N. communis									X			X		
N. pseudobtusa		X												
Ophidonais serpentina		X						X	X				X	X
Paranais littoralis		X												
P. simplex		X					X							
Piquetiella michiganensis	X	X		X			X	X	X	X	X	X		X
Pristina idrensis								X						
Slavina appendiculata								X	X					
Specaria josinae		X						X	X		X	X		
Stylaria lacustris		X					X	X	X	X	X	X		
Uncinais uncinata		X		X			X	X	X	X	X	X		X
Tubificidae														
Aulodrilus americanus		X		X				X	X		X	X		X
A. limnobius	X	X				X		X	X		X			X
A. pigueti									X				X	X
A. pluriseta		X						X	X					X
Ilyodrilus templetoni									X			X		
Limnodrilus spp.														
L. cervix		X		X					X				X	
L. claparedianus		X		X					X			X	X	
L. hoffmeisteri		X		X				X	X		X	X	X	X
L. profundicola		X		X				X	X		X	X	X	X
L. udekemianus		X									X	X		
L. spiralis													X	
Peloscolex ferox				X				X	X		X		X	X
P. freyi		X					X		X			X		
P. multisetosus								X						
P. superiorensis		X						X			X			
P. variegatus								X	X					

continued

Table A-13 (continued)

	Location													
Taxa	1	2	3	4	5	6	7	8	9	10	11	21	Munising	Marquette
Potamothrix moldaviensis				X							X	X		
P. vejdovskyi		X		X				X			X			X
Rhyacodrilus coccineu				X					X					X
R. montanus								X	X		X		X	X
Tubifex ignotus						X		X						
T. kessleri americanus									X			X		
T. tubifex		X							X			X	X	X
Immature w/o capilliform chaetae		X		X		X	X	X	X		X	X	X	X
Immature w/capilliform chaetae		X		X				X	X		X	X	X	X
Immature Tubificidae														
Hirudinea														
Glossiphoniidae														
Glossiphonia complanata									X					
Helobdella stagnalis								X	X					X
Placobdella sp.												X		
Pisicolidae														
Piscicola milneri								X						
Erpobdellidae														
Dina sp.								X	X					
Nephelopsis obscura									X					
Arthropoda														
Arachnoidea														
Hydracarina				X					X		X	X		X
Crustacea														
Ostracoda				X			X	X	X		X			
Mysidacea														
Mysis oculata			X			X		X						
Isopoda														
Asellus sp.								X	X		X		X	X
Lirceus sp.									X				X	
Amphipoda														
Gammarus sp.				X				X	X					X
Hyallela azteca									X				X	
Pontoporeia affinis	X	X	X	X	X	X	X	X	X	X	X		X	X
Insecta														
Plecoptera									X					
Capniidae														
Perlidae														
Paragnetina media		X							X					
Ephemeroptera														
Baetidae														
Baetis sp.								X		X				
B. intercalaris		X												

continued

Table A-13 (continued)

Taxa	1	2	3	4	5	6	7	8	9	10	11	21	Munising	Marquette
	Location													
Caenidae														
Tricorythodes sp.								X						
Ephemeridae														
Hexagenia limbata								X	X					
Heptageniidae														
Stenonema sp.			X											
S. tripunctatum		X												
Glossosomatidae														
Glossosoma sp.													X	
Trichoptera														
Helicopsychidae														
Helicopsyche borealis									X					
Hydropsychidae														
Cheumatopsyche sp.			X	X				X						
Hydroptilidae														
Agraylea sp.								X						
Leptoceridae														
Oecetis sp.							X		X		X		X	
Phryganeidae														
Phryganea sp.									X					
Phylocentropidae														
Phylocentropus sp.		X						X						
Polycentropus sp.									X				X	
Coleoptera														
Elmidae														
Dubiraphia sp.		X												
Macronychus glabratus										X				
Optioservus sp.		X												
Haliplidae														
Peltodytes sp.								X						
Diptera														
Tipulidae			X											
Ceratopogonidae		X						X	X					
Chironomidae														
Tanypodinae														
Ablabesmyia sp.		X						X	X			X	X	X
Larsia sp.		X												
Procladius sp.		X	X					X	X	X	X		X	X
Thienemannimyia gr.			X					X	X				X	X
Zaurelimya sp.		X	X						X					X
Diamesinae														
Monodiamesa cfr. depectinata		X						X	X	X	X	X		X
Monodiamesa sp.								X		X		X		
M. cfr. prolilobata		X						X		X	X	X		
M. cfr. tuberculata		X	X	X			X	X		X	X	X		X
Ondontomesa cfr. fulva									X			X	X	

continued

Table A-13 (continued)

Taxa	Location													
	1	2	3	4	5	6	7	8	9	10	11	21	Munising	Marquette
Potthastia cfr. longimanus		X					X	X	X	X	X	X		X
Prodiamesa sp.														
P. cfr. olivacea									X			X	X	
Protanypus sp.						X			X		X		X	
Pseudodiamesa sp.									X				X	
Unknown genus								X						
Orthocladiinae														
Cricotopus sp.		X		X				X	X	X		X	X	X
Eukiefferiella sp.		X												
Genus 1				X				X						
Heterotrissocladius														
H. cfr. changi	X	X	X	X	X		X	X	X	X	X	X		
H. cfr. oliveri						X								
Microcricotopus sp.								X					X	X
M. sp. 2									X					
Paracladius cfr. alpicola								X	X			X		
Paracladius cfr. triquetra			X					X						X
Parakiefferiella sp.			X					X				X		
Psectrocladius sp.		X						X	X	X		X		X
Thienemanniella sp.									X					
Chironominae														
Chironomini														
Unknown genus								X				X		
Chironomus sp.		X	X	X	X			X	X	X	X		X	
C. anthracinus gr.								X	X	X		X	X	X
C. fluviatilis gr.		X					X	X		X		X		X
C. plumosus gr.									X					
Cryptochironomus sp.				X			X	X	X	X	X	X	X	X
Cryptocladopelma sp.		X												X
Cryptotendipes sp.								X	X					
Demicryptochironomus cfr. vulneratus				X				X	X					X
Dicrotendipes sp.		X		X			X	X	X	X		X		X
Harnischia sp.								X						
Microtendipes sp.							X	X	X					
Microtendipes sp. 2									X					
Nilothauma sp.								X						
Pagastiella sp.		X						X	X					
Parachironomus cfr. demeijerei		X							X					
Paracladapelma cfr. winnelli		X	X										X	
P. cfr. galaptera													X	
P. cfr. nais													X	X
P. cfr. undine													X	X
Paracladopelma spp.	X	X	X	X	X	X	X	X	X	X	X	X		
P. nereis												X		
P. cfr. tylus							X							

continued

Table A-13 (continued)

Taxa	Location													
	1	2	3	4	5	6	7	8	9	10	11	21	Munising	Marquette
Paralauterborniella sp.		X							X					
Paratendipes sp.									X			X	X	
Phaenopsectra sp.		X						X	X			X	X	
P. (Tribelos) sp.		X						X	X				X	
Polypedilum fallax	X					X		X	X			X		X
P. *hatterale*									X					
P. *simulans* gr.									X				X	
P. *scalaenum* gr.		X		X				X	X		X	X	X	X
P. sp.		X	X					X	X					
P. cfr. *convictum*		X	X						X					
P. cfr. *nebeculosum*									X				X	
P. cfr. *illinoense*							X							
Pseudochironomus sp.									X		X			
Stictochironomus sp.		X	X	X	X			X	X	X	X	X		
S. sp. 2														
Tanytarsini														
Cladotanytarsus sp.				X			X	X	X		X	X	X	
Micropsectra sp.	X	X		X	X		X		X		X	X	X	
Protanypus													X	
Stempellina sp.				X							X			
Stempellinella cfr. *minor*									X					X
Tanytarsus sp.	X	X		X			X	X	X	X	X	X	X	
T. curvicornis									X				X	X
pupae	X					X	X	X	X	X	X	X	X	X
Simulidae									X					
Mollusca														
Gastropoda														
Physidae														
Physa sp.									X				X	
Limnaeidae														
Lymnaea sp.									X					
Stagnicola sp.									X					
Planorbidae														
Gyraulus sp.									X					X
Helisoma sp.									X					
Menetus sp.									X					
Viviparidae														
Campeloma sp.									X					X
Valvatidae														
Valvata sincera				X				X	X		X		X	X
V. tricarinata				X				X	X		X			X
Bulimidae														
Amnicola sp.								X	X					X
Pelecypoda														
Sphaeriidae														
Pisidium spp.	X	X		X		X	X	X	X		X		X	X
Sphaerium sp.									X				X	

Table A-14. Summary of benthic macroinvertebrates in nearshore Lake Superior, 1974 and 1975.

	Chironomidae		Oligochaeta		Sphaeriidae		Pontoporeia		Hyalella & Gammarus		Others		Total	
Location	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa
Black River Location 1 - 1974														
Station #														
6	234	5	303	4	76	1	196	1	0		13	2	822	13
Ontonagon Location 2 - 1974														
Station #														
1	76	3	6	1			6	1					89	29
2	75	5	12	2							37	3	124	10
3	340	10	5121	12			25	1			6	1	5492	24
4	428	9	3053	5			19	1			19	2	3519	17
5	197	5	948	5			146	1			6	1	1298	12
6	815	15	3928	9	25	1	196	1					4964	26
7	240	7					101	1					341	8
8	114	7	69	4			19	1					202	12
9	665	12	1577	8	13	1	57	1			12	2	2324	24
10	1241	16	6640	11	51	1	76	1					8008	29
11	784	12	1748	10	25	1	95	1			6	1	2658	25
12	689	14	2413	9			63	1					3165	24
Location mean $\overline{x}$	472		2320		10		67		0		7		2682	
SD (Standard Deviation)	367		2194		16		60				11		2511	
Upper Portage Entry Location 3 - 1974														
Station #														
1	114	9	13	1			6	1			12	2	145	13
2	37	4					70	1			6	1	113	6
3	6	1					32	1					38	2
4	241	7					6	1					247	8
Location Mean $\overline{x}$	100		3		0		29		0		5		136	
SD (Standard Deviation)	105		7				30				6		87	

continued

Table A-14 (continued)

Location	Chironomidae		Oligochaeta		Sphaeriidae		Pontoporeia		Hyalella & Gammarus		Others		Total	
	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa
Presque Isle Location 8 - 1974														
Station #														
1	1339	29	6371	10	703	1	6	1	203	1	210	11	8832	53
2	809	19	1344	9	6	1	374	1	25	1	57	4	2615	35
3	1454	20	804	12	6	1	57	1			12	2	2333	36
4	1223	25	1367	18	25	1	25	1			62	5	2702	50
5	772	12	531	5	13	1	184	1	13	1	18	3	1531	23
6	169	12	329	5	6	1	868	1			18	3	1390	22
7	203	10			6	1	310	1			6	1	525	13
Location Mean $\bar{x}$	853		1535		109		261		34		55		2847	
SD (Standard Deviation)	522		2191		262		303		75		72		2751	
Munising Location 9 - 1974														
Station #														
1	1102	7	52,086	7	114	1	6	1			3344	4	56,652	20
2	646	10	3953	7	1121	1	494	1	228	1	1013	4	7455	24
3	89	3	50	2	63	1	1778	1			138	4	2113	11
4	51	4	291	2	133	1	937	1			50	2	1462	10
5	106	5	481	7	152	1	1273	1			31	2	2043	16
6	658	5	760	2	51	1	3496	1					4965	9
7	1800	22	1699	6	1188	1	2774	1			460	7	7913	36
8	1773	17	6460	13	133	1	57	1	25	1	727	9	9175	42
9	2086	26	3615	11	272	1	462	1	13	1	900	11	7348	51
10	2640	9	9018	11	462	1			285	2	5377	12	17,782	35
11	126	10	1278	14	44	1	89	1			44	1	1581	27
12	386	8	13,485	8	304	1			13	1	202	6	14,390	24
13	1195	22	1393	5	608	1	342	1	6	1	607	12	4151	42
Location Mean $\bar{x}$	974		7275		357		900		44		992		10,541	
SD (Standard Deviation)	869		14,741		391		1141		95		1489		14,719	
Grand Marais Location 10 - 1974														
Station #														
1	200	11	37	3			89	1			6	1	332	16
3	56	5	101	3									157	8
6	189	7	392	6							6	1	587	14
Location Mean $\bar{x}$	148		177		0		30		0		4		359	
SD (Standard Deviation)	80		189				51				3		216	

continued

Table A-14 (continued)

Location	Chironomidae		Oligochaeta		Sphaeriidae		Pontoporeia		Hyalella & Gammarus		Others		Total	
	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa
Lower Portage Entry Location 4 - 1974														
Station #														
1	1330	5	38	1			95	1			38	2	1501	9
2	251	8	525	13	431	1	760	1	6	1	305	5	2278	29
3	506	7	214	5	13	1	336	1			89	5	1158	19
4	213	12	792	6	203	1	513	1			210	4	1931	24
Location Mean $\overline{x}$	575		392		161		426		2		161		1717	
SD (Standard Deviation)	520		334		171		281		3		120		490	
Eagle Harbor Location 5 - 1974														
Station #														
3	215	6	13	1			716	1			19	1	963	9
Isle Royale Location 6 - 1974														
Station #														
1	58	4	107	3	13	1	228	1			6	1	412	10
3	31	2	19	2	13	1	215	1			13	1	291	7
4	44	1	31	2	19	1	101	1			19	1	214	6
Location Mean $\overline{x}$	44		52		15		181		0		13		306	
SD (Standard Deviation)	14		48		3		70				7		100	
Big Bay Location 7 - 1974														
Station #														
1	150	4					57	1			6	1	213	6
3	276	11	651	8	76	1	272	1			31	2	1306	23
Location Mean $\overline{x}$	213		326		38		165		0		19		760	
SD (Standard Deviation)	89		460		54		152				18		773	

continued

Table A-14 (continued)

Location	Chironomidae		Oligochaeta		Sphaeriidae		Pontoporeia		Hyalella & Gammarus		Others		Total	
	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa
Whitefish Point Location 11 - 1974														
Station #														
1	468	11	942	12	89	1	82	1			146	4	1727	29
3	361	14	3743	8	32	1	779	1			354	5	5269	29
6	82	5	1400	9	1083	1	1697	1			13	1	4275	17
Location Mean $\overline{x}$	304		2028		401		853		0		171		3757	
SD (Standard Deviation)	199		1502		591		810				172		1827	
Carp River, Marquette Location 21 - 1974														
Station #														
1	1511	21	2952	12			6	1			6	1	4475	35
2	462	9	75	4			25	1					562	14
3	279	13	139	5			38	1			19	1	475	20
4	697	16	317	4			13	1					1027	21
5	467	15	182	7			6	1					655	23
6	379	10	829	8			32	1			6	1	1246	20
7	600	12	373	6			57	1	6	1	13	1	1049	21
Location Mean $\overline{x}$	628		695		0		25		1		6		1356	
SD (Standard Deviation)	413		1026				19		2		7		1405	
Marquette Harbor - 1975														
Station #														
1	2380	22	3212	18	101	1	393	1	500	2	202	8	6706	52
2	366	15	2304	14	101	1	51	1	57	1	157	6	3036	38
3	139	6	19	2	6	1	19	1			6	1	189	11
4	197	7	164	5	6	1	348	1			25	2	740	16
Location Mean $\overline{x}$	771		1425		53		190		139		98		2639	
SD (Standard Deviation)	1077		1585		56		209		242		97		2998	
Munising Harbor - 1975														
Station #														
1	1632	20	23,864	7	1064	1			351	3	56	4	26,967	32
2	114	4	247	3	165	1	716	1	13	1	38	1	1293	10
3	267	4	410	9	76	2	1070	1					1823	13
4	165	3	405	8	89	1	1393	1			6	1	2058	12
Location Mean $\overline{x}$	545		6232		349		795		91		25		8035	
SD (Standard Deviation	728		11,755		479		598		173		27		12,625	

Table A-15. List of phytoplankton species found in nearshore Lake Huron spring and fall, 1974.

- Chlorophyta
  - *Ankistrodesmus convolutus*
  - *A. falcatus*
  - *A. spiralis*
  - *Cerasterias irregularis*
  - *Chlamydomonas globosa*
  - *C. polypyrenoideum*
  - *C. snowii*
  - *C. sp*
  - *C. sp 1*
  - *C. sp 2*
  - *Chlorella ellipsoidea*
  - *Closteriopsis longissima*
  - *Closterium gracile*
  - *C. parvulum*
  - *Coelastrum dubium*
  - *C. kuetzingianum*
  - *C. microporum*
  - *C. reticulatum*
  - *C. sphaericum*
  - *Cosmarium contractum*
  - *C. formulosum*
  - *C. psuedoprotuberans*
  - *C. subtumidum*
  - *C. sp.*
  - *Crucigenia apiculata*
  - *C. quadrata*
  - *C. tetrapedia*
  - *Dactylococcus infusionum*
  - *D. sp.*
  - *Dictyosphaerium ehrenbergianum*
  - *D. pulchellum*
  - *Dispora crucigenioides*
  - *Elakatothrix gelatinosa*
  - *E. viridis*
  - *E. sp.*
  - *Franceia droescheri*
  - *F. ovalis*
  - *Gloecystis ampla*
  - *G. gigas*
  - *G. major*
  - *G. sp.*
  - *Golenkinia paucispina*
  - *G. radiata*
  - *G. sp.*
  - *Hyalotheca mucosa*
  - *Kirchneriella contorta*
  - *K. lunaris*
  - *K. obesa*
  - *Lagerheimia ciliata*
  - *L. citriformis*
  - *L. guadriseta*
  - *L. longiseta*
  - *L. subsalsa*
  - *Micractinium pusillum*
  - *Mougeotia americana*
  - *M. elegantula*
  - *M. sp.*
  - *Oocystis borgei*
  - *O. elliptica*
  - *O. pusilla*
  - *O. submarina*
  - *Pediastrum biradiatum*
  - *P. boryanum*
  - *P. duplex*
  - *P. duplex var. gracilimum*
  - *P. tetras*
  - *Scenedesmus abundans*
  - *S. acuminatus*
  - *S. acutiformis*
  - *S. armatus*
  - *S. bijuga*
  - *S. dimorphus*
  - *S. longus*
  - *S. obliquus*
  - *S. opoliensis*
  - *S. quadricauda*
  - *Schroederia setigera*
  - *Sphaerocystis schoeteri*
  - *Staurastrum chaetocercus*
  - *S. dejectum*
  - *S. furcigerum*
  - *S. paradoxum*
  - *S. polymorphum*
  - *S. sebaldi*
  - *Stipitococcus vasiformis*
  - *S. sp.*
  - *Tetraedron arthrodesmiforme*
  - *T. caudatum*
  - *T. minimum*
  - *T. pentaedricum*
  - *T. prescottii*
  - *T. trigonum*
  - *T. sp.*
  - *Tetrastrum glabrum*
  - *T. heteracanthum*
  - *T. regulare*
  - *Ulothrix subconstricta*
  - *U. subtilissima*
  - *U. sp.*
  - Unknown Chlorophyta

- Bacillariophyta
  - *Achnanthes affinis*
  - *A. clevei*
  - *A. flexella*
  - *A. hungarica*
  - *A. lanceolata*
  - *A. minutissima*
  - *A. sp.*
  - *Amphora ovalis*
  - *A. ovalis var. lybica*
  - *A. perpusilla*
  - *A. veneta*

Table A-15 (continued)

A. sp.
Amphipleura pellucida
Amphiprora ornata
Anomoeneis vitrea
Astrionella formosa
Attheya zachariasi
Cocconeis diminuta
C. pediculus
C. placentula
C. sp.
Coscinodiscus rothii
Cyclotella antiqua
C. caspia
C. comensis
C. comta
C. glomerata
C. kutzingiana
C. meneghiniana
C. michiganiana
C. ocellata
C. pseudostelligera
C. stelligera
C. striata
C. sp.
C. sp. 1
Cymatopleura solea
Cymbella affinis
C. cesatii
C. cuspidata
C. inaequalis
C. mirocephala
C. postata
C. tumida
C. tumidula
C. turgida
C. ventricosa
C. sp.
Denticula elegans
D. tenuis
Diatoma elongatum
D. tenue
D. vulgare
Diploneis elliptica
D. marginestriata
D. oculata
D. puella
Epithemia sp.
Fragilaria capucina
F. construens
F. crotonensis
F. harrissonii
F. intermedia
F. lapponica
F. leptostauron
F. pinnata
F. vaucheriae
F. sp.
Gomphonema angustatum
G. olivaceum
G. sp.
Gyrosigma sp.
Melosira granulata
M. islandica
M. varians
Meridion circulare
Navicula cryptocephala
N. cryptocephala var. veneta
N. decussis
N. elginensis
N. exigua
N. gregaria
N. hustedii
N. lanceolata
N. menisculus
N. placentula
N. pupula
N. radiosa
N. reinhardtii
N. subtilissima
N. tripunctata
N. tuscula
N. viridula
Neidium affine
N. iridis
Nitzschia acicularis
N. bacata
N. filiformis
N. fonticola
N. gracilis
N. kutzingiana
N. linearis
N. palea
N. sinuata
Opephora martyi
Rhizosolenia longiseta
R. longiseta
Rhoicosphenia curvata
Stephanodiscus astraea
S. astraea var. minutula
S. dubius
S. hantzschii
S. invisitatus
Surirella ovata
S. ovata
S. robusta
S. sp.
Synedra acus
S. amphicephala
S. cyclopum
S. delictissima
S. radians
S. rumpens
S. tenera
S. ulna
S. vaucheriae
S. sp.
Tabellaria fenestrata
T. flocculosa
Unknown Bacillariophyta

Cyanophyta
Anabaena flos-aquae
A. planctonica
A. subcylindrica
A. wisconsinense
A. sp.
Aphanocapsa delicatissima
A. elachista
Aphanothece clathrata
A. microspora
A. nidulans
A. prasina
A. sp.
Chamaesiphon confervicola
Chroococcus dispersus
C. kuetzingianum
C. limneticus
C. minor
C. minutus
C. prescottii
Coelosphaericum naegelianum

Table A-15 (continued)

- *Cyanarcus hamiformis*
- *Dactylococcopsis acicularis*
- *D. fascicularis*
- *D. smithii*
- *D. sp.*
- *Gomphosphaeria aponina*
- *G. lacustris*
- *Lyngbya contorta*
- *Merismopedia convoluta*
- *M. punctata*
- *Microcystis aeruginosa*
- *M. flos-aquae*
- *M. incerta*
- *Oscillatoria acutissima*
- *O. angusta*
- *O. angustissima*
- *O. prolifica*
- *O. splendida*
- *O. tenuis*
- *O. sp.*
- *Phormidium mucicola*
- *P. tenue*
- Unknown blue-green

Chrysophyta
- *Chrysosphaerella longispina*
- *Dinobryon bavaricum*
- *D. caudata*
- *D. divergens*
- *D. sertularia*
- *D. sociale*
- *D. stipitatum*
- *D. tabellariae*
- *Mallomonas acaroides*
- *M. alpina*
- *M. caudata*
- *Ophiocytium capitatum*
- *Stipitococcus vasiformis*
- *Synura ulvella*
- *S. sp.*

Cryptophyta
- *Chroomonas nordstedtii*
- *Cryptomonas erosa*
- *C. ovata*
- *C. sp.*
- *Rhodomonas minuta*

Pyrrophyta
- *Ceratium hirundinella*

Euglenophyta
- *Euglena sp.*
- *Phacus sp.*

Chloromonadophyta
- *Gonyostomum semen*
- Unknown flagellates

Table A-16. Abundance of phytoplankton by class in Lake Huron, 1974.

Location (#)	Month	Sample Type	Number of Samples	Mean Phytoplankton unit/ml	Mean Chlorophyta unit/ml	Mean Bacillariophyta unit/ml	Mean Cyanophyta unit/ml	Mean Chrysophyta unit/ml
Detour (12)	July	g	3	2,386	208	1,239	180	251
		c	2	805	22	467	74	137
	Sept	g	3	2,066	254	788	323	157
		c	3	2,267	206	1,240	311	112
Cheboygan (13)	July	g	3	1,692	43	971	62	387
		C	2	1,680	328	900	112	456
	Sept	g	3	1,936	124	400	475	38
		c	3	2,445	193	788	634	59
Presque Isle (14)	July	g	3	1,804	143	771	109	446
		c	3	2,529	244	1,078	167	596
	Sept	g	3	1,417	153	614	214	190
		c	3	1,577	145	707	182	294
Alpena (15)	July	g	3	14,407	444	4,907	8,163	79
		c	3	12,786	592	2,904	8,026	136
	Sept	g	3	4,049	300	2,813	227	190
		c	3	3,892	213	2,182	363	419
Harrisville (16)	July	g	3	3,063	37	2,004	89	634
		c	3	1,463	21	779	62	454
	Sept	g	3	3,130	414	1,355	318	905
		c	3	3,165	316	1,343	510	919
Tawas (17)	July	g	3	3,053	165	2,272	124	226
		c	3	4,712	142	2,414	64	147
	Sept	g	3	3,829	660	1,657	474	854
		c	3	3,816	691	1,685	406	800
Saginaw Bay (18)	July	g	4	4,198	1,886	734	657	379
		c	5	4,142	1,487	846	363	800
	Sept	g	4	7,609	1,571	2,216	3,362	42
		c	3	16,953	4,551	4,365	6,942	182
Harbor Beach (19)	July	g	3	3,380	136	2,646	44	179
		c	3	5,142	177	4,036	14	301
	Sept	g	5	3,813	203	2,082	209	1,045
		c	1	2,568	136	1,120	282	878
Lexington (20)	July	g	3	3,857	128	3,232	248	61
		c	2	3,106	44	2,436	290	86
	Sept	g	2	6,335	325	3,911	854	838
		c	2	4,400	180	2,960	430	620

g = grab sample
c = composite sample

continued

Table A-16 (continued)

Station (#)	Month	Sample Type	Number of Samples	Mean Cryptophyta unit/ml	Mean Pyrrophyta unit/ml	Mean Euglenophyta unit/ml	Mean Chloromonadophyta unit/ml	Mean Unknown unit/ml
Detour (12)	July	g	3	488				21
		c	2	104				
	Sept	g	3	533				12
		c	3	382				17
Cheboygan (13)	July	g	3	79				
		c	2	142				
	Sept	g	3	899				
		c	3	769	2			
Presque Isle (14)	July	g	3	299	1			35
		c	3	398				36
	Sept	g	3	245	2			
		c	3	249				
Alpena 15)	July	g	3	713				101
		c	3	1,019				109
	Sept	g	3	502				9
		c	3	714				
Harrisville (16)	July	g	3	229				70
		c	3	134			5	7
	Sept	g	3	136				
		c	3	77				
Tawas (17)	July	g	3	229				36
		c	3	1,945				
	Sept	g	3	155	2			28
		c	3	208				20
Saginaw Bay (18)	July	g	4	541				2
		c	5	622	2	1		23
	Sept	g	4	376	5			37
		c	3	669	6			239
Harbor Beach (19)	July	g	3	309		17	49	
		c	3	579			35	
	Sept	g	5	274				
		c	1	148	4			
Lexington (20)	July	g	3	175				10
		c	2	217				34
	Sept	g	4	388				19
		c	2	190				20

g = grab sample
c = composite sample

Table A-17. Zooplankton species presence in nearshore Lake Huron, spring and fall, 1974.

Location:	12		13		14		15		16		17		18		19		20	
Species	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F
Rotatoria																		
Conchilidae																		
Conchilus unicornus		X		X	X	X	X	X	X	X	X	X				X		X
Filinidae																		
Filinia longiseta	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Synchaetidae																		
Polyarthra vulgaris	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gastropidae																		
Gastropus stylifer				X				X	X					X	X			
Asplanchnidae																		
Asplanchna priodonta	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Brachionidae																		
Brachionus calcyiflorus	X	X	X	X		X	X	X		X		X	X	X	X	X	X	X
Kellicottia longispina	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
Keratella cochlearis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cladocera																		
Leptodoridae																		
Leptodora kindtii	X	X	X				X											
Polyphemoidae																		
Polyphemus pediculus										X								
Holopedidae																		
Holopedium gibberum	X	X		X				X		X				X		X		X
Daphnidae																		
Ceriodaphnia lacustris								X				X					X	
Dapinia longiremus					X	X						X	X					
D. galeata mendotae	X			X					X	X			X	X			X	X
D. retrocurua	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X
Bosminidae																		
Bosmina longirostris	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
Bosmina coregoni				X						X	X	X	X					
Copepoda																		
Calanoida																		
Centropagidae																		
Limnocalnus macrurus											X			X		X		
Temoridae																		
Epischura lacustris	X	X	X	X	X	X		X	X	X		X	X			X		X
Diaptomidae																		
Diaptomus ashlandi							X						X			X	X	
D. minutis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. oregonensis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. sicilis	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X
Cyclopoida																		
Tropocyclops praisinus					X	X							X	X	X			
Cyclops bicuspidatus thomasi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nauplii	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mysidacea																		
Mysidae																		
Mysis relicta								X										

Table A-13. Abundance of zooplankton by major taxonomic groups in nearshore Lake Huron, 1974.

Location (# of Stations)	Ratio of Calanoids to Cyclopoids + Cladacerans S*	F*	Mean total # Organisms/m³ S*	F*	Mean # Rototoria/m³ S*	F*	Mean # Cladocera/m³ S*	F*	Mean # Calanoida/m³ S*	F*	Mean # Cyclopoida/m³ S*	F*	Mean # Nauplii/m³ S*	F*	Mean # Mysidae/m³ S*	F*
Background																
Detour (3)	0.70	0.71	5144	3898	1265	1369	528	489	779	457	858	430	1714	1126	-	-
Presque Isle (3)	0.65	0.89	7403	3772	1167	1610	430	239	1342	640	1821	565	2643	718	-	-
Harrisville (3)	1.04	0.53	6076	5691	1893	2017	233	928	791	682	676	794	2483	1270	-	-
Lexington (3)	0.38	0.57	29,981	8778	1690	4726	11,589	876	4156	684	4765	796	7781	1696	-	-
Impacted																
Cheboygan (3)	0.41	0.28	6310	3633	1082	1487	400	503	838	273	1824	691	2166	679	-	-
Alpena (3)	0.55	0.27	4803	6044	2513	2167	507	1135	271	434	322	1007	1190	1299	-	2
Harbor Beach (3)	0.44	0.43	44,147	11,187	2593	5524	20,156	1644	3544	895	2467	1227	15,387	1897	-	-
Tawas (3)	0.48	0.52	18,131	11,254	2237	3185	5920	2350	1664	1525	1552	1630	6758	2564	-	-
Saginaw Bay (4)	0.41	0.35	18,253	10,156	1684	2456	4038	1886	3020	1099	4792	2071	4719	2644	-	-

* S = Spring
F = Fall

Table A-19. Macroinvertebrate presence in nearshore Lake Huron at Detour (12), Cheboygan (13), Presque Isle (14), Alpena (15), Harrisville (16), Tawas (17), Harbor Beach (19), and Lexington (20) during 1974 and Calcite, Harbor Beach and Alpena in 1975.

	LOCATIONS										
Taxa	12	13	14	15	16	17	19	20	Calcite	Harbor Beach	Alpena
Coelenterata											
Hydridae		X									
Platyhelminthes											
Tricladida		X	X	X		X	X				
Nematoda	X	X	X	X	X		X	X	X		
Annelida											
Oligochaeta											
Enchytraeidae	X	X				X					
Lumbriculidae											
Eiseniella tetraedra						X					
Stylodrilus heringianus	X	X	X	X	X	X	X	X	X		X
Naididae											
Amphichaeta leydigii								X			
Arcteonais lomondi		X		X		X	X				X
Nais sp.		X		X		X	X				X
N. alpina											X
N. barbata				X							
N. communis		X									X
N. elinguis											X
Dero digitata											X
D. nivea											X
Ophidonais serpentina				X							X
Piguetiella michiganensis		X		X		X		X	X		X
Slavina appendiculata				X				X			X
Specaria josinae		X		X							
Stylaria lacustris		X				X					
Uncinais uncinata	X	X		X	X	X					X
Tubificidae											
Aulodrilus americanus		X		X		X					X
A. limnobius				X		X	X				
A. pigueti		X		X		X	X				X
A. pluriseta		X		X			X				X
Ilyodrilus templetoni							X				
Limnodrilus angustipenis							X				
L. cervix		X		X			X			X	X
L. claparedianus							X			X	X
L. hoffmeisteri		X	X	X			X	X	X	X	X
L. maumeensis				X			X				X
L. profundicola				X			X			X	X
L. spiralis				X							
L. udekemianus		X				X					X
Peloscolex ferox		X		X	X	X			X		X
P. freyi		X			X	X	X				
P. multisetosus		X		X		X					
P. variegatus						X	X				
Potamothrix moldaviensis		X		X		X	X				X
P. vejdovskyi		X	X	X	X		X	X		X	X
Rhyacodrilus montanus											
R. coccineus											X

continued

Table A-19 (continued)

	LOCATIONS										
Taxa	12	13	14	15	16	17	19	20	Calcite	Harbor Beach	Alpena
R. sodalis										X	
Tubifex kessleri americanus		X									
T. tubifex		X				X					
T. ignotus				X		X					
Immature w/o capilliform chaetae		X	X	X	X	X	X	X	X	X	X
Immature w/capilliform chaetae		X	X	X		X	X	X		X	X
Hirudinea											
Glossiphoniidae											
Batrachobdella picta		X									
Glossiphonia complanata						X					
Helobdella stagnalis		X				X		X			X
Erpobdellidae											
Dina sp.		X									
Arthropoda											
Arachnoidea											
Hydracarina	X	X									
Crustacea											
Isopoda											
Asellus sp.		X		X		X					X
Lirceus sp.		X				X					
Amphipoda											
Gammarus sp.		X		X		X					X
Hyalella azteca		X		X	X	X			X		
Pontoporeia affinis	X		X	X		X			X		X
Decapoda											
Orconectes virilis		X		X							
Insecta											
Ephemeroptera											
Caenidae											
Caenis sp.		X									
Ephemeridae											
Ephemera simulans		X									
Hexagenia limbata		X									X
Heptageniidae											
Stenonema sp.								X			X
S. tripunctatum		X									
Leptophlebiidae											
Leptophlebia sp.					X						
Hemiptera											
Corixidae		X					X	X			
Hesperocorixa sp.		X									
Trichoptera											
Hydropsychidae											
Cheumatopsyche sp.		X			X						
Leptoceridae											
Mystacides sp.		X									
M. sepulchralis						X					
Oecetis sp.		X		X	X	X					X
Polycentropodidae											
Polycentropus sp.	X						X				
Coleoptera											
Elmidae											

continued

Table A-19 (continued)

Taxa	LOCATIONS										
	12	13	14	15	16	17	19	20	Calcite	Harbor Beach	Alpena
Dubiraphia bivittata				X							
Stenelmis sp.				X							
Diptera											
Chaoboridae											
Chaoborus sp.				X							
Chironomidae											
Tanypodinae											
Ablabesmyia sp.				X		X		X			X
Pentaneura sp.		X									
Procladius sp.		X	X	X		X	X	X		X	X
Thienemannimyia gr.		X		X		X	X				
Diamesinae											
Monodiamesa cfr. depectinata		X									X
M. cfr. tuberculata	X					X					
Potthastia cfr. longimanus		X		X	X	X					X
Protanypus sp.	X		X								
Orthocladiinae											
Cricotopus sp.							X		X		X
Heterotrissocladius cfr. changi	X	X	X	X	X	X			X		X
Paracladius trequetras											X
Parakiefferiella sp.		X				X			X		X
Psectocladius sp.						X				X	X
Chironominae											
Chironomini											
Chironomus sp.								X			
C. anthracinus gr.		X					X			X	X
C. fluviatilis gr.				X		X		X			X
C. plumosus gr.		X		X		X	X			X	X
Cryptochironomus sp.		X		X	X	X	X			X	X
Crypotocladopelma sp.				X							X
Cryptotendipes sp.				X							
Demicryptochironomus sp.		X				X					
Dicrotendipes sp.		X	X	X	X	X	X		X		X
Harnischia sp.						X					X
Microtendipes sp.		X			X	X	X				
Nilothauma sp.		X				X		X			
Parachironomus sp.		X									
Paracladopelma sp.	X	X	X		X	X					X
P. undine									X	X	X
P. nias											X
Paralauterborniella											X
Paratendipes sp.		X					X				X
Phaenopsectra tribelos sp.		X								X	X
Polypedilum cfr. fallax									X		X
P. hatterale					X						
P. simulans gr.					X		X	X	X		X
P. scalaenum gr.		X				X	X	X			X
P. nebeculosum											X
Pseudochironomus sp.		X			X	X	X	X	X		X
Stictochironomus sp.		X		X		X	X				
Tanytarsini											

continued

Table A-19 (continued)

Taxa	12	13	14	15	16	17	19	20	Calcite	Harbor Beach	Alpena
Cladotanytarsus sp. 1		X				X	X	X		X	X
C. sp. 2		X									
Micropsectra sp.	X		X		X						
Rheotanytarsus sp.		X								X	X
Stempellina cfr. *bauei*								X			
Stempellinella cfr. *minor*		X									X
Tanytarsus sp.	X			X	X	X	X	X		X	X
T. cfr. *curvicornis*						X					X
Pupae	X								X	X	X
Mollusca											
Gastropoda											
Physidae											
Physa sp.		X		X		X					
Planorbidae											
Gyraulus sp.		X				X					
Valvatidae											
Valvata sincera			X						X		
V. tricarinata		X		X					X		X
Bulimidae											
Bulimis									X		X
Amnicola sp.		X		X							
Lymnaea sp.									X		
Pleuroceridae											
Goniobasis livescens		X									
Pleurocera acuta								X			
Pelecypoda											
Unionidae											
Anodonta sp.		X									
Lasmigona sp.		X									
Lampsilus siliquoidea		X									
Sphaeriidae											
Pisidium sp.		X	X	X		X			X		X
Sphaerium rhombeideum		X							X		
S. similis		X									

Location	Chironomidae		Oligochaeta		Sphaeriidae		Pontoporeia		Hyalella & Gammarus		Others		Total	
	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa
Detour Location 12 - 1974														
Station #														
6	754	6	298	3			19	1			12	2	1083	12
Cheboygan Location 13 - 1974														
Station #														
1	583	12	3427	6	44	1					6	1	4060	20
3	399	6	1595	7	133	1			563	2	273	8	2963	23
4	460	16	1050	10	114	1			1799	2	865	16	4288	45
5	347	14	334	4	19	1			13	1	120	5	833	25
6	1073	21	1583	8	342	3			2546	2	3541	15	9085	49
7	588	13	922	13	63	2			950	1	1064	15	3657	44
Location Mean $\overline{x}$	575		1497		119				979		978		4148	
SD (Standard Deviation)	262		1053		117				1019		1324		2722	
Presque Isle Location 14 - 1974														
Station #														
6	132	6	1412	3	1780	1	4231	1			18	3	7573	14
Alpena Location 15 - 1974														
Station #														
1	107	4	3965	11	6	1					25	3	4103	19
2	62	5	3536	13									3598	18
3	19	2	12,261	7	25	1					18	3	12,323	13
4	44	1	2179	7									2223	8
5	113	5	11,248	8									11,361	13
6	81	6	2919	11									3000	17
7	260	6	4451	13	13	1							4724	20
8	454	7	5750	11	209	1					44	3	6419	19
9	557	9	2888	13	89	1	6	1			37	4	3577	29
10	253	10	5024	12			6	1	463	2	70	4	5816	35
Location Mean $\overline{x}$	195		5422		34		1		46		19		5714	
SD (Standard Deviation)	184		3509		67		3		146		24		3468	

continued

Table A-20 (continued)

Location	Chironomidae		Oligochaeta		Spaeriidae		Pontoporeia		Hyalella & Gammarus		Others		Total	
	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa	No./m²	No. Taxa
Harrisville Location 16 - 1974														
Station #														
6	284	11	201	5					6	1	24	4	515	21
Tawas Location 17 - 1974														
Station #														
1	56	3	113	5					83	2	44	4	296	14
2	492	11	113	5	25	1			209	2	195	6	1034	25
3	360	8	328	7					95	2			783	17
4	221	9	550	6	13	1			38	1	26	2	848	19
5	1163	16	1344	9	19	1			108	1	50	2	2684	29
6	493	10	367	5			13	1	133	1			1006	17
7	94	5	88	3					19	1			201	9
Location Mean $\bar{x}$	411		415		8		1.86		98		45		979	
SD (Station Deviation)	375		411		11						69		820	
Harbor Beach Location 19 - 1974														
Station #														
1	44	2	2956	12							13	1	3013	15
2	557	6	6619	8							13	1	7189	15
3	266	4	5833	7									6099	11
4	487	5	4549	7							6	1	5042	13
7	310	4	1592	5							19	1	1921	10
9	1287	11	2457	6							25	1	3769	18
10	241	2	2583	6									2824	8
Location Mean $\bar{x}$	456		3798								11		4265	
SD (Station Deviation)	403		1894								9		1911	
Lexington Location 20 - 1974														
Station #														
6	279	10	264	7							37	5	580	22

continued

Table A-20 (continued)

Location	Chironomidae		Oligochaeta		Sphaeriidae		Pontoporeia		Hyalella & Gammarus		Others		Total	
	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa	No./m^2	No. Taxa
Alpena - 1975														
Station #														
1	1101	16	1825	16	19	1					13	1	2958	34
2	1361	13	2237	10	203	1							3801	24
3	2869	15	4129	13	652	2	6	1	12	2	63	3	7731	36
4	766	18	692	6	89	3	44	1			19	2	1610	30
5	714	9	4002	10							6	1	4722	20
6	900	9	1689	13	557	2			6	1	6	1	3158	26
Location Mean $\bar{x}$	1285		2429		253		8		3		18		3998	
SD (Standard Deviation)	811		1366		283		18		5		23		2097	
Calcite Harbor - 1975														
Station #														
1	Lost													
2	Lost													
3	Lost													
4	151	5	120	9	12	1	13	1	6	1	95	5	397	22
Harbor Beach - 1975														
Station #														
1	1843	7	10,976	5									12,819	12
2	714	7	2059	4									2773	11
3	31	4	13	1									44	5
Location Mean $\bar{x}$	863		4349										5045	
SD (Standard Deviation)	915		5829										6824	